Bulletin

of

The Geological Society of America

VOLUME 55 AUGUST 1944 NUMBER 8

CONTENTS

PAGES

Contact metamorphism at Rye Patch, Nevada. By Charles J. Vitaliano.. 921–950

Morrison formation and related deposits in and adjacent to the Colorado Plateau. By William Lee Stokes 951–992

Correlation charts prepared by the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*

Correlation of the Cambrian formations of North America. By the Cambrian Subcommittee, B. F. Howell, *Chairman* 993–1004

Correlation of the Cretaceous formations of the Greater Antilles, Central America, and Mexico. By Ralph W. Imlay 1005–1046

Subscription, $10 per year.

Publication Office: Mt. Royal and Guilford Aves., Baltimore 2, Md.

Communications for publication should be addressed to The Geological Society of America, Dr. H. R. Aldrich, Secretary, 419 West 117th Street, New York 27, N. Y.

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Entered as second-class matter in the Post-Office at Baltimore, Md., under the Act of Congress of July 16, 1894.

Accepted for mailing at special rate of postage provided for in Section 1103, Act of October 3, 1917, authorized on July 8, 1918.

9. Hornblende lamprophyre 933
10. Sketch map showing distribution of rock types in outer contact area 934
11. Section along north wall of Rye Patch Agnes Canyon 936
12. Cross section through outer contact zone in South Panther Canyon 937
13. Garnet in tactite 939
14. Garnet and diopside in tactite 939
15. Radiating aggregates of diopside 939
16. Tourmaline-bearing pegmatite 944
17. Tourmaline in quartz vein from outer contact zone 946
18. Silicified and pyritized limestone 946
19. Silicified lens in limestone 947
20. Plan of tungsten occurrences 948

ABSTRACT

In the Rye Patch area in the west-central part of the Humboldt Range, Nevada, Triassic (?) limestones interbedded with silty layers have been intruded by igneous rocks, the principal type being a quartz monzonite. The quartz monzonite is surrounded on the north, east, and south by an aureole of contact metamorphism. On the western side faulting has cut the intrusion so that any metamorphic rocks which may have been formed are not seen at the surface. A long narrow contact zone east of the aureole extends northward a considerable distance.

Metamorphic changes range from recrystallization of limestone to complete replacement by contact silicates. The contact-metamorphic minerals include garnet, diopside, epidote, clinozoisite, idocrase, tremolite, recrystallized calcite, quartz, and minor scheelite.

The sediments are deformed by the intrusion into a small northerly trending arch. Aplite dikes and quartz veins appear related to the arching and also to the formation of scheelite.

INTRODUCTION

In the mineralized area accompanying the Rye Patch intrusion, both invading and invaded rocks are well exposed. Study of such a region should yield information of value in the interpretation of the mineral processes responsible for the associated tungsten mineralization and at the same time contribute to a better understanding of the stages of contact metamorphism in the Humboldt Range.

This investigation has comprised the study of: (1) the original sediments; (2) igneous intrusions; (3) contact-metamorphic products; (4) paragenetic sequence of the contact-metamorphic minerals; (5) reasons for the localization of the metamorphism; and (6) later phases of the igneous invasion—namely, the pegmatitic and hydrothermal phases, including most of the tungsten mineralization.

Tungsten mineralization along the western slope of the Humboldt Range may be associated with two granitic intrusions. The Rocky Canyon intrusion, essentially quartz monzonite (Jenney, 1935, p. 37), lies north and east of the Oreana tungsten mine, while the Rye Patch intrusion, also quartz monzonite, lies about 10 miles to the north of the Rocky Canyon intrusion along Rye Patch Agnes Canyon.

Portions of the summers of 1938 and 1939 were spent in the field mapping parts of the area in detail. The mineral relationships have been further investigated in the laboratory microscopically, chemically, and by X-rays.

The writer is deeply indebted to Professor Paul F. Kerr of Columbia University, who suggested the problem and who has given helpful criticism both in the field and in the preparation of the report; to Mr. Charles H. Segerstrom, president, and Mr. Ott F. Heizer, general manager, of the Nevada-Massachusetts Mining Company,

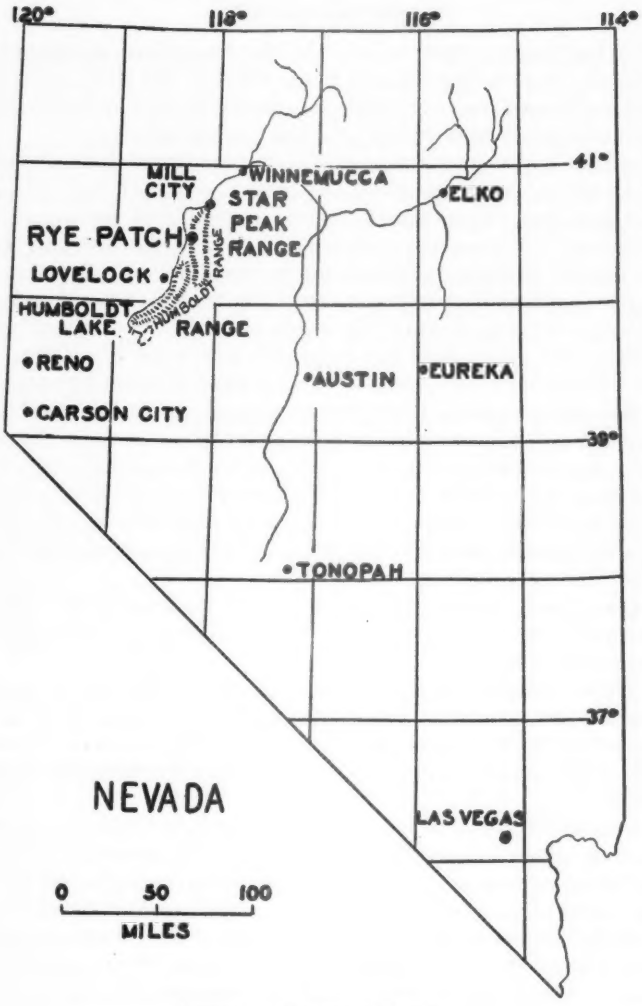


FIGURE 1.—*Index map of Nevada*
Showing the location of the area studied

with whose kind permission the writer stayed as a guest at Tungsten, Nevada; to Mr. Donald W. Davis of Columbia University, who assisted in the field during the summer of 1938; to Mr. Charles Shortino of Rye Patch, Nevada, for information concerning the mining operations in the area under discussion and permission to examine the Rye Patch Agnes workings; and to Columbia University, for the award of the James Furman Kemp Fellowship in Geology, through which this investigation was made possible.

GENERAL GEOLOGY

The Rye Patch area is largely underlain by blue, thin-bedded, northeasterly striking limestones, the prevailing dip being to the west. In Rye Patch Agnes Canyon, a roughly oval-shaped area of brownish rock of about 20 acres marks the outcrop of the quartz monzonite here described as the Rye Patch intrusion.

The intrusion has produced two areas of contact-metamorphic rock, separated by a zone of relatively unmetamorphosed limestone. The first of these (called in this paper the inner area) contains some tactite and recrystallized limestone but is chiefly light silicate rock. It appears to surround the intrusion on the north, east, and south sides but does not outcrop on the western side because of faulting. The second (called the outer area) is linear in outcrop with a trend parallel to the strike of the sediments and is situated east of the first area. It is composed more abundantly of tactite but also contains light silicate rocks with appreciable recrystallized limestone.

Aplite and pegmatite dikes, along with quartz veins, represent later stages of the quartz monzonite intrusion. Pegmatites are limited to the border of the intrusion, while the aplites and quartz veins are more prominent in the rocks some distance removed. Some sulphide and tungsten mineralization has accompanied vein filling, and an attempt is being made to work sulphide-bearing veins containing silver in the Rye Patch Agnes mine. Tungsten mineralization is almost lacking in the immediate vicinity of the intrusion, but some scheelite is found in the quartz veins associated with the aplite dikes to the northwest.

Two other types of intrusive rocks, whose effect on the limestone has been negligible in contrast to that of the quartz monzonite, are dikes of an older metadiorite and a younger camptonite.

The broader structural features are shown on the map (Fig. 2). In general, the limestone and its metamorphic derivatives strike rather uniformly N. 15° E. ($\pm 10°$) and dip 46° to 74° W. Across these dipping beds the surface of the monzonite intrusion, which occupies rougly the center of the map, rises from west to east at an angle of 12°.

The intrusion is bordered by an aureole of metamorphosed limestone, exceptionally wide near the middle of the northern rim. This wide triangular area coincides with an anticlinal bulge in the beds, the axis of which pitches toward the intrusion.

If the surface of the intrusion continued as a methematical plane with the dip as indicated, the outcrop should continue up the valley. Since it does not, either the intrusion dips into the hill at a lesser angle or ends here. The recurrence of metamorphosed limestone 500 feet to the east suggests that here either the same intrusion or an offshoot once again comes close to the surface (Fig. 11).

Near the eastern end of the outcrop of the intrusion, steeply inclined dikes lead off toward the NNE. and SSE., along fractures that essentially parallel the beds and the near-by contact of the limestones and the quartz monzonite. The whole feature is too small to warrant speculation concerning its origin other than that the fractures opened as a consequence of the intrusion itself. A few quartz dikes occupy related directions as do several small faults.

The intrusion is cut off near the western margin of the map by a normal fault that dips about 45° W.

SEDIMENTARY STRATA

Thin-bedded blue calcareous limestones with some intercalated silty beds cover most of the area. Later calcite veinlets are often present. Microscopically the limestone strata are almost entirely fine-grained calcite (chemical tests show only a trace of magnesium) with carbonaceous impurities and minor quartz. The more silty members contain varying amounts of quartz in addition to the carbonate.

The sediments are covered by valley alluvium on the west and abut against the Weaver rhyolite of the Koipato series on the east. The limestones are a continuation of those described by Ransom (1909, p. 31–32), Knopf (1924, p. 29), Jenney (1935, p. 29–30), and Kerr (1938, p. 398), in the area immediately to the south. Jenney assigned them to the upper Middle Triassic of the Star Peak formation, on the basis of a fauna representing the *Daonella dubia* zone. Near the mouth of Rye Patch Canyon a few coiled cephalopods were found, but they were too poorly preserved for identification.

The contact between the limestone and the Weaver rhyolite where it crosses Panther Canyon suggests that the sediments overlie the rhyolite disconformably. At Rye Patch, part of the contact between the limestone and the rhyolite is faulted, but exposures in other places immediately adjacent on either side of the contact suggest the existence of a slight angular unconformity, although the actual contact is not well exposed. Wheeler (1936, p. 394) tentatively assigns the Weaver formation to the late Paleozoic, on the basis of this disconformity and on the absence of volcanics in the lower Star Peak formation. Cameron (1939, p. 579) classifies the rhyolite formation as either Upper Paleozoic or Triassic.

INTRUSIVE ROCKS

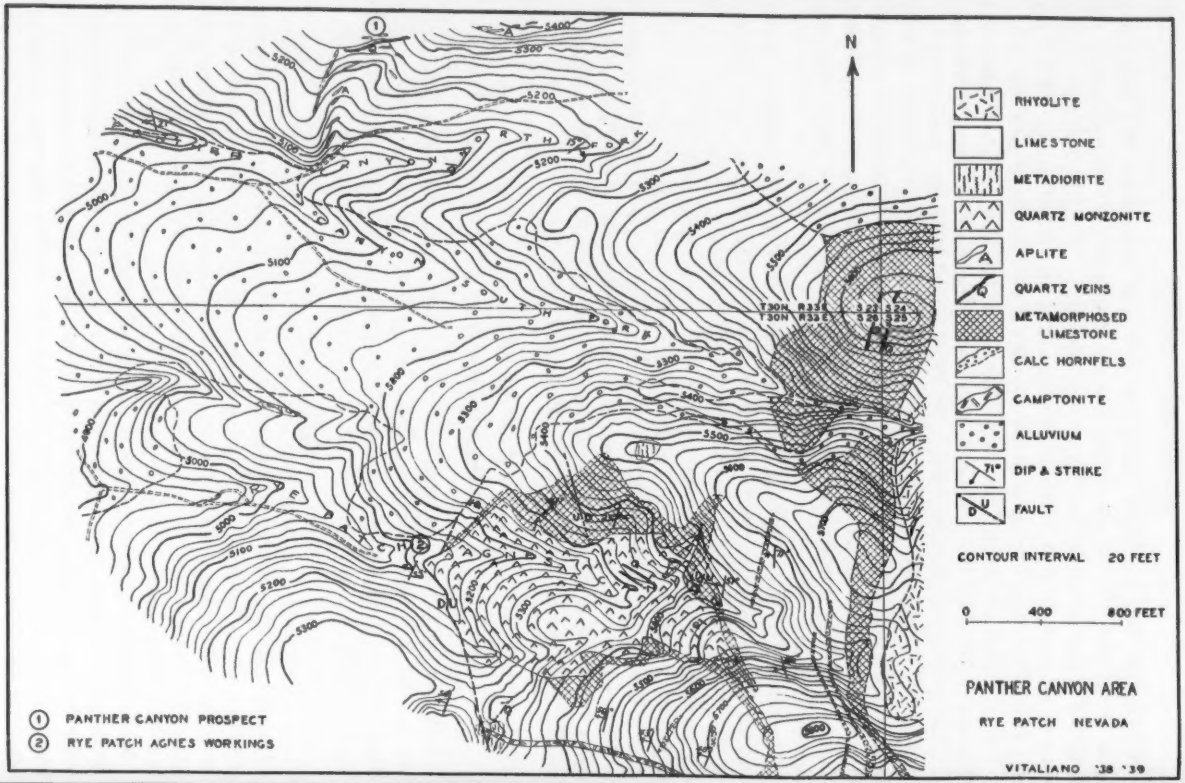
GENERAL STATEMENT

Both acid and basic rocks intrude the sedimentary strata of the Rye Patch area. The earliest is a metamorphosed diorite, exposed in two small outcrops. The largest and most important is the quartz monzonite, found in Rye Patch Agnes Canyon. Dikes of camptonite are the latest igneous rock.

METADIORITE

One outcrop of metadiorite is situated about 1300 feet northeast of the main portal of the Rye Patch Agnes Mine (Fig. 3), and the other lies about 900 feet to the south-southeast. The latter is cut on the west by a fault which also truncates the western part of the inner contact area. In the south-southeast the metadiorite appears to be cut by later dikes.

Mineralogically, the metadiorite is chiefly oligoclase showing albite twinning, fibrous actinolite, biotite, and magnetite. Small amounts of sphene, epidote, zircon, and some apatite, along with infrequent interstitial quartz which locally may be present in fair amount, are accessory. The amphibole (Fig. 4A) occurs in sheaves similar to that in the metadiorite of the Rochester district (Knopf, 1924, p. 31). Another facies is composed of quartz and feldspar grains averaging 0.02 mm. in diameter between folia of chlorite. In all sections the schistosity is very marked (Fig. 4B).


N
RHYOLITE
LIMESTONE
METADIORITE
QUARTZ MONZONITE
APLITE
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METAMORPHOSED LIMESTONE
CALC HORNFELS
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ALLUVIUM
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2 RYE PATCH AGNES WORKINGS

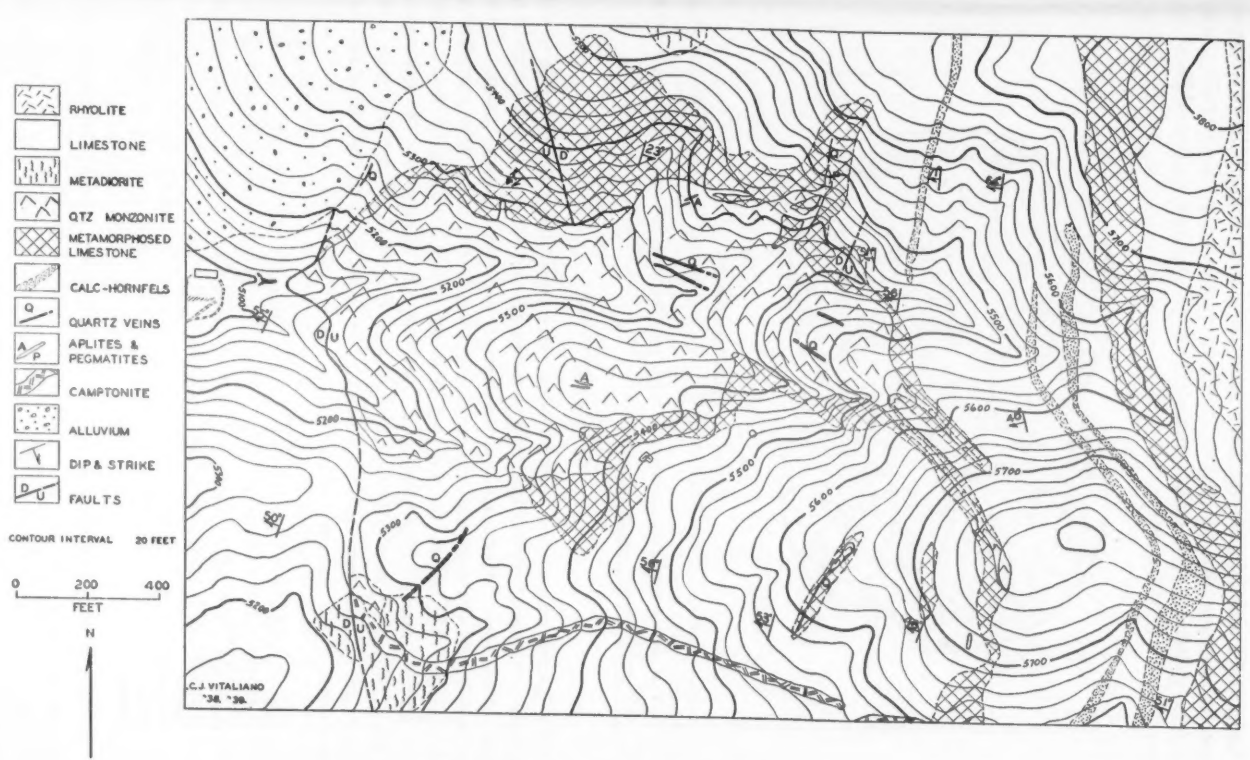
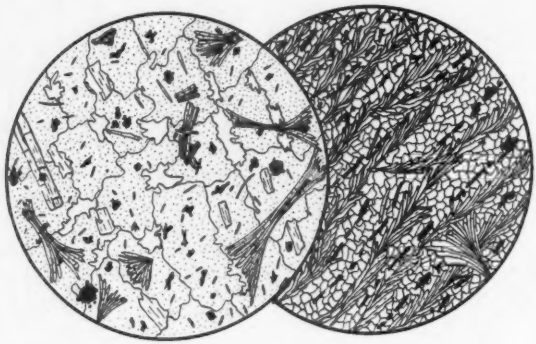


FIGURE 3.—*Geologic map of Rye Patch intrusion*

Knopf (1924) dated the metadiorite as Triassic or earlier because of its metamorphic character and connected it with the Triassic igneous activity. Kerr (1938, p. 398) and Jenney (1935, p. 30) described rocks of the same type from the central Humboldt Range, just south of Rye Patch.



A B

FIGURE 4.—*Metadiorite phases*

A. Maculose phase:—quartz, white; oligoclase, spotted; actinolite, sheaf like aggregates; biotite, dashed lines; magnetite, black. × 15.

B. Schistose phase:—chlorite, lath like grains; actinolite, sheaf like aggregates; quartz and feldspar, uncolored; epidote, black. × 15.

Diagrammatic sketches from microscopic field.

QUARTZ MONZONITE

The quartz monzonite is light-colored, medium-grained, composed of quartz, feldspar, and mica. Orthoclase, oligoclase, microcline, and microperthite make up most of the rock. Myrmekite and free quartz occur in anhedral grains. Biotite and some accessory minerals—sphene, apatite, magnetite, and pyrite—complete the mineralogy. The biotite occurs in well-developed grains averaging 5.0 mm. in length and showing marked absorption—(X) colorless, (Y) dark green, (Z) dark green. Both sericitization and carbonation of the feldspars occur along fractures, while biotite grains have been slightly corroded. The following is an analysis of this rock determined by the traverse method:

	Per cent		*Per cent*
Quartz	24.8	Apatite	0.2
Oligoclase	21.4	Epidote	0.1
Microperthite	19.6	Calcite	0.1
Orthoclase	17.5	Hematite	0.1
Microcline	9.0	Chlorite	0.1
Biotite	5.9	Zircon	tr.
Magnetite	0.6		
Muscovite	0.5	Total	100.1
Sphene	0.2		

Jointing is well developed in the northeastern part of the intrusion: The joints fall into two patterns: one set strikes N. 25° E. and dips 48° ESE., and the other strikes N. 70° E. and dips 65° NNW. Near the northern edge of the intrusion proper some small aplite dikes parallel the latter set of joints.

The quartz monzonite has been intruded into the limestone strata. At the eastern edge of the limestone the contact can be seen in numerous exposures and conforms to the bedding of the sediments (Fig. 5). The western contact is obviously faulted, as indicated by the existence of a crush zone (Fig. 5).

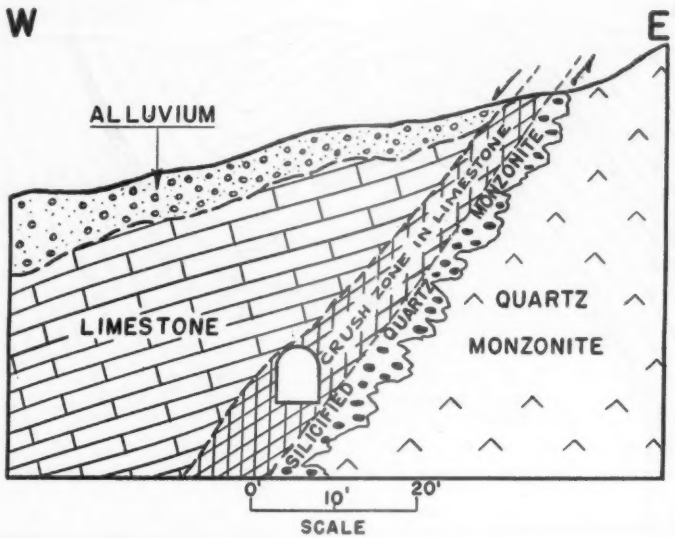


FIGURE 5.—*Diagrammatic representation of the western contact of the quartz monzonite*
The crush zone and the zone of silicified monzonite are shown

Exposures on the northern side of Rye Patch Canyon clearly indicate that in the upper reaches of the intrusion the limestone beds have been pried apart by the invading magma. Arching of the sedimentary rocks has been accompanied by fracturing of the competent beds and drag folding of the incompetent (Fig. 6). The extension of the arch northward is believed to be due to the continuance of this sill-like character of the intrusion.

A petrographic comparison with the Rocky Canyon intrusion about 10 miles south of this area shows that the Rye Patch rock is finer-grained, more compact, and contains a little more biotite than the former, but otherwise the two appear to be substantially the same. Probably both extend downward to the same granite mass.

In the Rye Patch area, the lack of Mesozoic sediments later than Middle Triassic limits the quartz monzonite to post-Middle Triassic. Unless positive evidence to the contrary can be established, it is reasonable to assume that the quartz monzonite belongs to the same magmatic epoch as the widespread intrusions of western Nevada. These, according to many different investigators,[1] are probably post-Jurassic.

[1] Louderback (1904, p. 318); Spurr (1905, p. 133); Ball (1908, p. 42); Diller (1908, p. 90); Lindgren (1915, p. 14); Knopf (1924, p. 11); Kerr (1934, p. 14); Jenney (1935, p. 47); Ferguson and Muller (1936, p. 394); Gianella (1936, p. 43); Kerr (1938, p. 401).

APLITES

The aplite dikes either fill joints or occur at random throughout the quartz monzonite. They vary in width from 1 inch up to 1 foot. Aplites also occur about half a mile north of the intrusion, where they reach 2½ feet in width and where they have

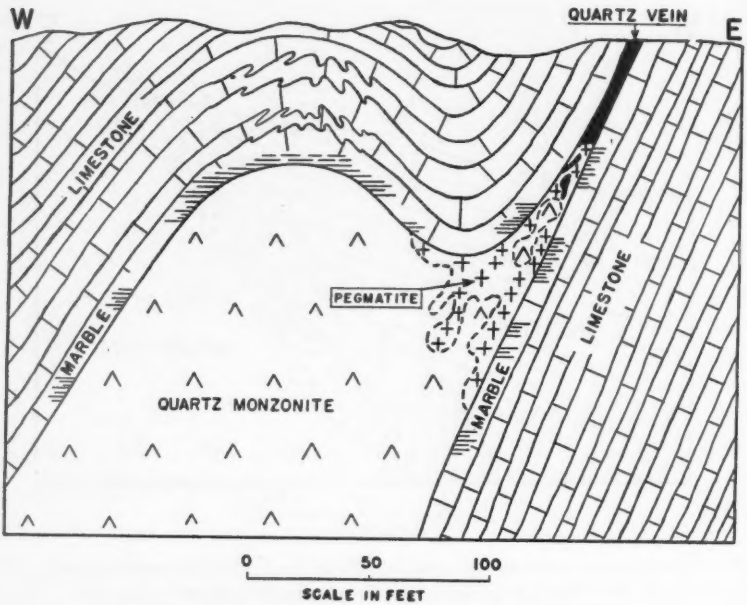


FIGURE 6.—*Section along north wall of Rye Patch Agnes Canyon*

Showing local arching of the overlying limestone beds over the intrusion. Note the conformable relation between the limestone and the intrusion which probably exists only in the upper reaches of the igneous mass.

invaded and altered the limestone. Here tungsten mineralization has resulted as a late phase of this invasion. Sill-like aplitic layers occur intercalated with the limestone immediately below a scheelite-bearing quartz vein and across the crest of the structural arch.

Quartz, orthoclase, microcline, oligoclase, and some microperthite make up most of the aplite, the remainder consisting of a few scattered grains of biotite and occasional muscovite. The texture is medium- to fine-grained.

PEGMATITES

Quantitatively, the pegmatite stage of the intrusion at Rye Patch has not been extensive. Unlike the aplites, the pegmatites are restricted to the immediate vicinity of the intrusion. They pass downward into the quartz monzonite, and upward into quartz veins (Fig. 7). The passage of pegmatites into the parent magmatic body, into quartz masses, or into aplites has been reported from many

areas. It is particularly characteristic of the Humboldt Range (Kerr, 1938). At Rye Patch, an excellent exposure shows the transition from the quartz monzonite into pegmatite, which in turn becomes more and more quartz-rich and passes finally into a quartz vein; the entire change is accomplished within 25 feet (Fig. 7).

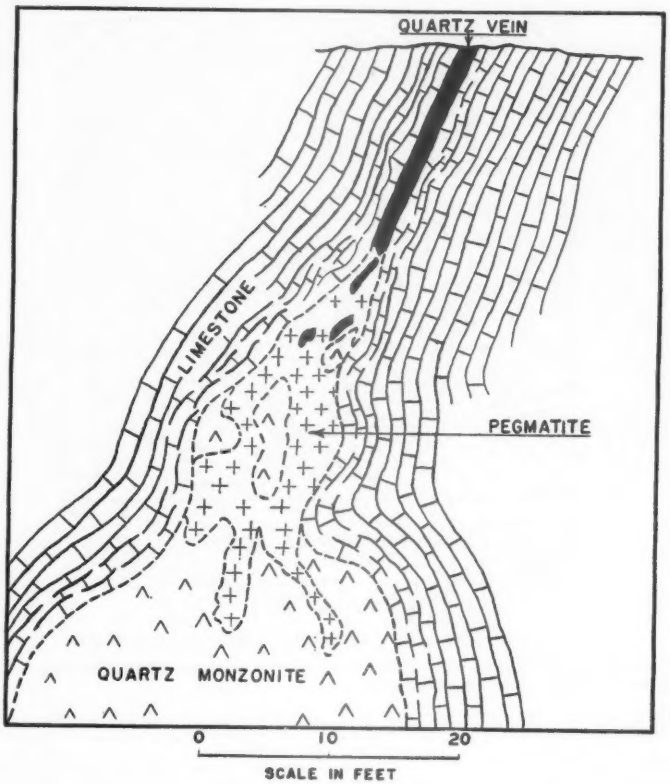


FIGURE 7.—*Pegmatite relations*

The sketch shows the gradation of pegmatite into quartz above and into quartz monzonite below. This change is very gradual, with small isolated patches of the new phase appearing first. These grow more numerous and larger, and pass finally into the solid mass.

LAMPROPHYRES

In many places basic dikes younger than the quartz monzonite are found. In the area mapped these have been found only in limestone. Immediately south of the area Jenney (1935, map) has shown these same dikes cutting the Rocky Canyon granite. The dikes are nearly always vertical and in some cases—*e.g.*, at the Rye Patch Mine—they follow fault planes. Their width never exceeds 25 feet. In several places schistosity is developed near the walls of the dikes. Occasionally, contact-metamorphic lime-silicate minerals are found at the contact. These new

minerals are patchy in distribution, idocrase generally being the most abundant (Fig. 8).

An east-west line, drawn just south of the Rye Patch intrusion, divides these dike rocks into two groups: Those north of this line contain hornblende and biotite, those

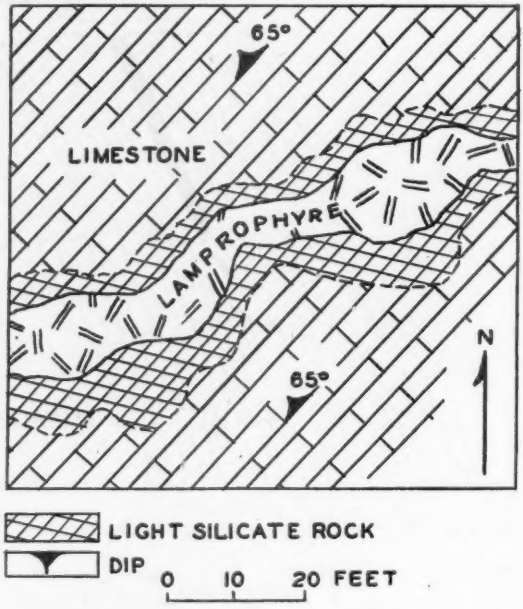


FIGURE 8.—*Contact metamorphism around lamprophyre dike*

Pace-compass map showing contact metamorphic phenomena produced by the intrusion of lamprophyre into the limestone. Occasional masses of idocrase are developed.

south of it biotite alone. The remaining minerals are the same. The feldspar is andesine ($n_\alpha = 1.549$, $n_\gamma = 1.558$), optically positive, showing excellent zonal development and twinned according to both the albite and pericline laws (Fig. 9). It and the ferromagnesian minerals occur both as phenocrysts and in the groundmass. Occasionally these minerals occur in two generations of phenocrysts (Fig. 9). Magnetite is the most prominent accessory mineral. Hydrothermal alteration has caused sericitization of the feldspar, carbonation of the feldspar and amphibole, and chloritization of the biotite and amphibole. Various stages of alteration may be seen, the extreme being carbonate pseudomorphs after andesine and hornblende. Weathering has oxidized magnetite to limonite, particularly along fractures. In view of the mineralogy it seems proper to classify these rocks as hornblende lamprophyre and mica lamprophyre, respectively.

Thin sections of a related dike rock occurring to the south near the portal of the

Rye Patch Mine were compared with those in the area mapped. Andesine and biotite form phenocrysts in this rock, while hornblende is absent. This dike was referred to by Ransome (1909, p. 44) as a diabase and mapped as such by Jenney (1935, map).

FIGURE 9.—*Hornblende lamprophyre*

Andesine, colorless or twinned; hornblende, cross-ruled. The dotted area represents very fine-grained groundmass in which some glass is present. A veinlet of later quartz traverses the rock. Diagrammatic sketch from microscopic field. X 30.

CONTACT METAMORPHISM

GENERAL STATEMENT

The intrusion of the quartz monzonite has resulted in three types of contact metamorphism: (1) the recrystallization of the original limestone; (2) the most widespread,—the formation of lime-silicate rocks, believed to represent the higher stages of contact metamorphism in the area; and (3) a slight development of calc-hornfels. The role of the lamprophyres in the contact-metamorphic history of the Rye Patch area has been negligible. Recrystallization of the limestone sometimes occurs without silicate mineralization, but the formation of silicate minerals requires a preceding or accompanying stage of recrystallization of the limestone.

The inner area of contact metamorphism surrounds the igneous rock on three sides. The outer area is linear and varies in width (Fig. 10). It starts southeast of the quartz monzonite and follows the strike of the sediments northward for approxi-

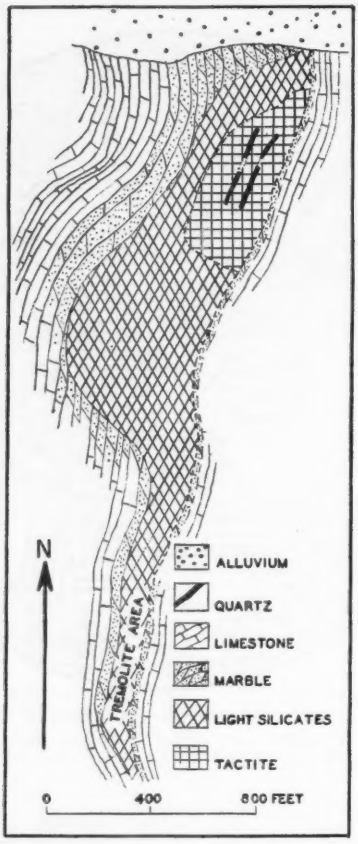


FIGURE 10.—*Sketch map showing distribution of rock types in outer contact area*

Tactite occurs in the northeast portion of the area, and grades westward and southward into light silicate rock. This passes on the west into marble, which in turn grades into unaltered limestone.

mately three-quarters of a mile. Between this and the inner area lies a strip of limestone about 400 to 600 feet wide, which is unmetamorphosed except for a few thin lenses of calc-hornfels.

RECRYSTALLIZED LIMESTONE

Large areas of white recrystallized limestone are scattered throughout the Rye Patch area. In the inner contact aureole, they occur on the northern and southern

sides of the intrusion. Two limestone pendants in the extreme northern part of the intrusion (Fig. 3) have been almost entirely recrystallized. In many instances, the marble comes into contact with the igneous rock. In the outer contact area, the northwestern margin is bordered by a band of marble about 300 feet wide.

Mineralogically, the marble is composed of irregular interlocking calcite grains, which vary in size depending upon the location of the rock, growing coarser toward the intrusion. Locally a few grains of silicate minerals, generally diopside, are scattered throughout the marble. The contact with almost pure limestone on the one side and the increase of silicate grains toward the main tactite mass on the other side suggest that these are the result of introduced mineralization.

Umpleby (1917, p. 66) raised the question of time continuity between marmorization and silication. He states:

> "Whether or not there was a distinct break between the two stages is not definitely determinable from the available evidence. . . . It is the opinion of the writer, however, that two separate and distinct epochs of magmatic emanations are represented. . . ."

At Rye Patch, however, the evidence seems to indicate little time between the two processes. This is especially apparent in thin section, where unaltered areas of limestone grade into contact silicate rock. In each instance studied, there is a distinct zone of marble between the unaltered and the silicated limestone. In some cases this zone is only 0.02 mm. wide, but it is invariably present. Evidently the advancing wave of contact silicate mineralization recrystallized the limestone at least at its front, and sometimes for a considerable distance in advance.

CALC-HORNFELS

Three layers of a brown, sugar-textured rock are observed in the sediments in the zone between the contact areas. These range from 6 to 20 feet in width. The rock in the three layers is fine-grained, averaging about 0.02 mm., and is composed largely of highly interlocking quartz and orthoclase with some calcite, epidote, and diopside in prominent fine-grained aggregates, accompanied by needles of actinolite, occasional grains of idocrase, some chlorite, antigorite, and a little sericite. The entire mass has been fractured, and later epidote, pyrite, and carbonate were introduced, while a definite quartz vein traverses one layer.

SILICATE ROCKS

Inner area.—In the inner area, well-developed masses of contact-metamorphic silicate rocks occur on the north and south sides of the intrusion. In exposures on the eastern side they are present but are not developed so extensively. At this contact the sediments lie conformably beneath the igneous rock. This fact may have restricted the upward spread of the metasomatic agents (Fig. 11).

At the western contact, however, no exposures of silicate minerals occur. The limestone here is composed almost entirely of unrecrystallized carbonate and some carbonaceous impurities, with a few scattered grains of diopside. Similar limestone occurs north and south of the intrusion and at the outer edge of the silicated area. Underground, the lower workings of the Rye Patch Agnes mine cross this contact. In the main tunnel, the limestone is separated from the quartz monzonite by a

prominent crush zone and a zone of silicified quartz monzonite (Fig. 5). A drift northerly from the main tunnel on this contact is reported to have encountered similar material along its entire length, some 75 feet, but the caving of this drift prevented verification of the report. A similar, though smaller, crush zone can be seen at the western margin of a small quartz monzonite satellite area about 500 feet directly

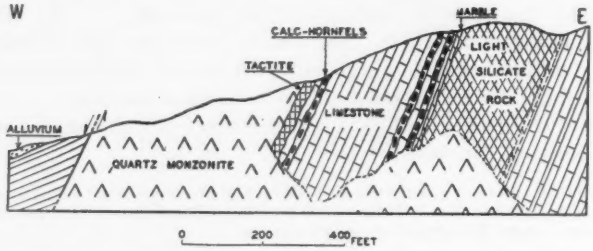


FIGURE 11.—*Section along north wall of Rye Patch Agnes Canyon*
Showing the exposed relations of the various rock types and their probable continuation in depth

south of the tunnel. The alignment and comparable attitude of these crush zones indicate a continuous fault.

The absence of more strongly silicated limestone at the western contact thus must be attributed to faulting rather than to selective replacement of the limestone. The silicification of the quartz monzonite along the fault without any corresponding alteration of the adjacent limestone indicates post-hydrothermal movement.

The highest stage of contact metamorphism is represented by tactite, which is mainly a medium-grained, grayish, compact rock, composed of epidote, garnet, and diopside accompanied by a few accessory minerals—feldspar, quartz, sphene, and apatite. At two or three scattered localities limited to the southern boundary of the quartz monzonite, coarse epidote and garnet occur. In one of these localities some scheelite has been found, but on the whole tungsten mineralization is absent in this zone. Occasional monomineralic masses of epidote or garnet, up to 6 inches in diameter, are encountered. Remnant masses of original limestone up to 2 or 3 inches in their largest dimension are encountered in the tactite of this area. These still retain the grain size, bedding, and carbonaceous impurities of the sediments and are always rimmed by marble.

The light silicate rocks are usually composed of idocrase, light-colored garnet, fine-grained epidote, and diopside, with some quartz and orthoclase. No definite boundary can be drawn between these and the tactite. In a few places, widely scattered segregations of idocrase or tremolite are the only evidence of the light silicate zone. Unmetamorphosed remnants of limestone were not found in the light silicate rocks of this inner area.

Outer area.—On the whole, the same types of contact-metamorphic silicate rocks are represented as in the inner area, but they differ strikingly in areal distribution. The tactite is more limited in extent but mineralogically it is similar to that of the inner area although the texture is slightly coarser. On the south and west it passes into the light silicate zone (Fig. 10).

The light silicate rock in the northern part of the zone is composed of diopside, idocrase, feldspar, fine-grained epidote, and some quartz, while in the southern part of the zone tremolite and recrystallized calcite predominate. The decrease in the extent of silication to the south seems to indicate gradation to lower-temperature

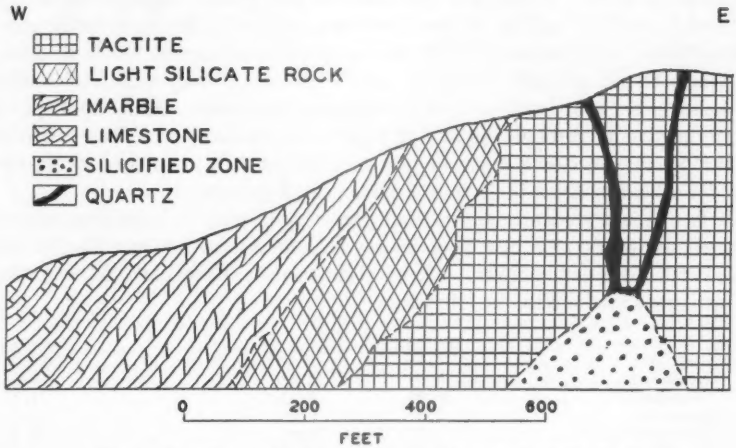


FIGURE 12.—*Cross section through outer contact zone in South Panther Canyon*

Showing gradation from the silicified zone in tactite, existing at the bottom of the canyon, into quartz veins (solid black), which are found on the upper walls of the canyon.

conditions. Associated with the tremolite marble are remnants of unmetamorphosed limestone up to 15 feet long.

The light silicate rock passes on the west into recrystallized limestone, which occurs in a broad band in the northern part and grows narrower southward (Fig. 12).

CONTACT METAMORPHIC MINERALS AND PARAGENESIS

Contact metamorphism involves, first, rising temperature and increasing amounts of volatile matter from the magma, until each reaches a maximum (but not necessarily both simultaneously), followed by a gradual decrease in temperature and emanations as the mass cools and crystallization progresses. Assuming the composition of the emanations to be nearly constant during a contact-metamorphic period, lower-temperature minerals would form first and would be replaced by higher-temperature forms until the maximum had been reached; then these would be replaced by lower-temperature minerals as the temperature fell. Some of these might be the same species that were formed during the rise of temperature, but in other cases irreversible reactions would prevent the reappearance of minerals replaced during the period of rising temperature. Fluctuations in temperature and in the character of the emanations would introduce additional complications. In any case, the descending order of minerals would be more clearly preserved, while the evidence for the ascending series might be entirely obliterated. Furthermore, the age relationships would be purely relative, since minerals of different temperature ranges might form simultaneously at different locations.

At Rye Patch, evidence for the complete paragenetic sequence is lacking. Probable relationships are as follows:

GARNET: Garnet is much more abundant in the inner area than in the outer. Although generally medium- to fine-grained in the former, some masses up to 2 cubic inches across occur. In the outer area, only the finer-grained variety is found. The mineral is typically reddish in hand specimen, and two different varieties may be distinguished when examined under the microscope—a massive brownish form, in part anisotropic, probably andradite, and a colorless, wholly anisotropic variety, probably grossularite, which occurs as veinlets in the former. About 10–15 per cent of all the massive garnet found at Rye Patch is truly anisotropic. This occurs only in two places—the one in the inner area, near the southern contact of the intrusion, and the other and larger in the northeastern part of the outer area.

It has been abundantly shown that garnet developed in contact-metamorphic lime-silicate zones, as a rule, contains several different molecules. The garnet at Rye Patch is similarly complex. Chemical and modal analyses of the purest available garnetiferous tactite gave the following:

	Per cent
Almandite	5.48
Grossularite	34.65
Andradite	35.99
Spessartite	2.48
Wollastonite	7.77
Diopside	2.80
Sphene	0.59
Quartz	10.38
Total	100.04

	Per cent
SiO_2	45.04
Al_2O_3	9.47
Fe_2O_3	11.36
FeO	2.38
CaO	29.50
MgO	0.51
MnO	1.17
TiO_2	0.22
H_2O	0.36
Total	100.01

The veinlets of colorless garnet indicate fracturing before the completion of the garnet stage. In addition, more fracturing occurred in a post-metasomatic stage, for the garnet is transected by later veinlets of hydrothermal epidote as well as quartz and still later carbonate (Fig. 13).

DIOPSIDE: Diopside is common at Rye Patch, where it occurs in all phases of the contact-metamorphic rocks and as a reaction mineral in the border phases of the quartz monzonite. Not very striking in the hand specimen, it appears microscopically as anhedral to euhedral colorless crystals, varying in size from extremely small particles to grains 1 millimeter long. Cleavage is well developed, and $Z \wedge c$ is slightly less than 40°. The indices of refraction are: $n_\alpha = 1.670$, $n_\beta = 1.677$, $n_\gamma = 1.698$ (diopside 92 per cent—hedenbergite 8 per cent).

Ordinarily the diopside is closely associated with garnet, epidote, and idocrase. Often veinlets of diopside transect the garnet (Fig. 14). In view of its widespread occurrence, diopside probably began to form before garnet and certainly ended after garnet. Veinlets of epidote cut the diopside.

Diopside also occurs as scattered grains in relatively unmetamorphosed limestone associated with a narrow rim of recrystallized calcite. Here, it probably represents the recrystallization of scattered original impurities in the limestone. Coarse radiating aggregates of diopside were obtained from a ledge in the northwestern part of the inner contact area (Fig. 15).

EPIDOTE (AND CLINOZOISITE): Epidote is widespread in the contact-metamorphic zones at Rye Patch, and it is also found in the quartz monzonite itself near the contact, where it is the result of endometamorphism. The grain size varies from fine

FIGURE 13.—*Garnet in tactite*

Garnet (G) transected by quartz (Q) and later calcite (C). Diagrammatic sketch from microscopic field. × 15.

FIGURE 14.—*Garnet and diopside in tactite*

Showing garnet (G) transected by diopside (D), and diopside inclusions in the garnet. Later quartz (Q); calcite (C). Diagrammatic sketch from microscopic field. × 15.

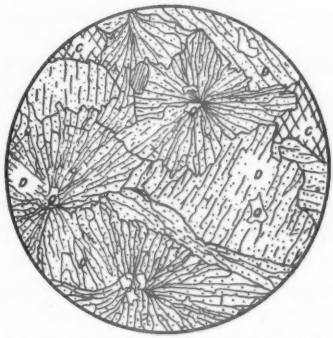


FIGURE 15.—*Radiating aggregates of diopside*

Quartz grains (Q) often occur at the centers of radiation. Interstitial calcite (C). Diagrammatic sketch from microscopic field. × 15.

to coarse, while the crystals are anhedral and distinctly pleochroic. In the inner contact area, epidote occurs only in the tactite, ranging from irregular grains associated with garnet and diopside to pure concentrations averaging 6 inches in diameter (rarely, up to 1 foot). In the outer contact area it is found in the light silicate rock as well as in the tactite. In the tactite, the medium- to coarse-grained pleochroic epidote (X, colorless; Y, green; Z, pistachio green) is closely associated with diopside, garnet, feldspar, early and late calcite, and a little quartz. Occasional grains are twinned parallel to (100). In the light silicate rock, epidote is almost always present as fine grains in linear arrangement. In addition to the granular type, both contact areas contain later veinlets of epidote.

The mutual boundary relationships suggest that the granular epidote replaces diopside and garnet and is in turn replaced by idocrase. The vein material, however, is definitely later than the feldspar. Epidote therefore seems to have been formed either in one long period which probably overlapped diopside and garnet during the contact metamorphism and continued into the hydrothermal stage, or in two distinct stages, one purely contact metamorphic, the other hydrothermal. Epidote sometimes occurs as a zone between grains of recrystallized calcite and feldspar. Here it must have been formed soon after the introduction of the feldspar, as a reaction rim between the latter and the carbonate. Later fracturing and alteration have affected all the epidote, as seen by the quartz and carbonate veins which transect and in some instances replace it.

CLINOZOISITE is not common. It is rather rare in the inner area, but is more abundant in the outer. Prismatic grains, often 2.0 mm. long, show the weak birefringence (0.01) and positive optic character which distinguish this mineral from epidote. The clinozoisite is commonly associated with true epidote and diopside. Colorless, nonpleochroic clinozoisite sometimes rims epidote. The iron content of the emanations must at one time have fallen too low to permit the continued formation of epidote, and clinozoisite formed instead.

TREMOLITE: Fibrous tremolite occurs as a contact mineral in association with recrystallized calcite, forming a tremolite marble in the southern part of the outer area. In the inner area it sometimes replaces diopside and, more often, coats slightly metamorphosed limestone.

The relative age of the tremolite is obscure, since a few grains of epidote and orthoclase are the only other such minerals found in the tremolite marble; but its presence in the zone of weakest metamorphism suggests that it may have formed there early, possibly before the anhydrous minerals were developed in the inner contact zone. According to Bowen (1940), it is characteristic of the lower-temperature stage of metamorphism. Radiating sheaves of tremolite of similar origin are found just north of Panther Canyon in silicified limestone.

SCHEELITE: The small amount of scheelite found in the tactite appears to have formed in a rather short period along with garnet, diopside, and epidote, possibly continuing after the epidote.

IDOCRASE (VESUVIANITE): Idocrase in euhedral elongated crystals is uniformly distributed throughout the light silicate rock of the outer area. In the inner area, it occurs largely in brown clusters varying up to 2 or 3 feet in their largest dimension. In this form it is found also in contact with the basic dike rocks and generally is the only contact-metamorphic mineral formed by these rocks. Identification was confirmed by X-ray diffraction patterns.

The boundary relations with epidote indicate that the idocrase was the later mineral to form. Its absence in the tactite seems to show that it was not formed during the period of highest temperature, but it may have been deposited in the earlier period of rising temperature, as well as after the epidote.

WOLLASTONITE: Wollastonite is not common in these contact-metamorphic rocks. Thin-section examination shows a colorless lath-like form which is, at least in part, definitely late, since it replaces diopside, epidote, clinozoisite, and idocrase. X-ray diffraction patterns were identical with known wollastonite.

CALCITE: The simplest, probably the earliest, change resulting from the intrusion of the limestone by the quartz monzonite was the recrystallization of the calcite. This is indicated by the occurrence of recrystallized calcite at every boundary between unaltered limestone and silicate rocks or mineral grains. The last feeble expression of contact metamorphism might also have been simple recrystallization of the calcite.

APATITE occurs in the inner area in small euhedral crystals not more than 0.05 mm. in length. The crystals usually consist of a brownish core, surrounded by a colorless rim, and are generally associated with sphene, epidote, and orthoclase. Apatite was not noted more than 5 feet from the contact, and then only in the neighborhood of the pegmatites.

SPHENE also occurs in the inner tactite near the quartz monzonite-limestone contact and, like the apatite, only in association with pegmatite. It is always found in small euhedral grains which show pleochroism (X, colorless; Y, brown; Z, brownish red). The small crystals of apatite and sphene occur in a matrix of quartz, feldspar, and carbonate between the larger grains of diopside and epidote. Their definite association with pegmatite seems to limit both minerals to this stage of igneous activity; but there is no reliable evidence for their exact place in the sequence with respect to the other minerals, which undoubtedly were forming over a longer period, including the pegmatite stage. The apatite and sphene are earlier than most of the feldspar and quartz, however.

FELDSPAR (orthoclase and microcline) and QUARTZ are interstitial to the lime silicate minerals and in veinlets traversing them. Their formation seems to have been insignificant until the pegmatite phase. The quartz becomes more prominent in the hydrothermal stage.

CHEMICAL CONSIDERATIONS

Although sufficient chemical data are not at hand to permit an accurate quantitative estimate of the changes occasioned by the metamorphism in the area, an approximate idea may be obtained by mineralogical examination.

The unaltered limestone contains, in addition to the calcium carbonate, carbonaceous impurities and some quartz. Magnesia is present only in traces. Recrystallization has involved chiefly the elimination of the carbonaceous impurities; examination of the recrystallized limestone indicates an absence of the myriad tiny opaque inclusions so characteristic of the original sediment. The formation of scattered grains of diopside may in part be attributed to the recrystallization of lime, magnesia, and silica of the original rock. With the quantitative increase of silicate minerals toward and including the tactite, addition of material from an outside source must be sought to account for all the substance needed.

The assemblage of minerals in the silicate zone requires the addition of silica, alumina, iron oxides, some magnesia, a little manganese, titania, chlorine, phosphorus, tungsten, fluorine, and water. It may be concluded, therefore, that these substances have been added to the sedimentary rocks from the intrusion in the process of contact metamorphism. At the same time, carbon dioxide was driven off.

The preservation of original structures of the sediments points to the retention of their volume practically intact. In many instances, especially in the outer area, the

original bedding and the attitude of the former sediments are preserved even in the tactite. Splendid examples of this phenomenon may be observed in Panther Canyon and south of Agnes Canyon. In the latter locality, remnants of limestone occur in the light silicate rock, and the bedding passes undisturbed from the unaltered rock into the silicated mass.

LOCALIZATION OF METAMORPHISM

The distribution of rock types in many areas of limestone contact metamorphism may be summarized by the following typical statement: "Certain beds retain nearly their original texture and composition close up to the [intrusion], while others are obviously altered for long distances from the intrusive contact" (Ransome, 1904, p. 84). The following relations are found at Rye Patch, where the distribution of metamorphic rock types is similarly complex:

(1) Two large areas of metamorphic rocks separated by a zone of limestone unmetamorphosed except for—

(2) Three layers now completely changed to calc-hornfels.

(3) A definite zonal arrangement of silicate minerals and recrystallized limestone in the outer area.

(4) Irregular distribution of the metamorphic rocks of the inner area.

(5) Small scale local alterations of the metamorphosed and unmetamorphosed beds near the intrusion.

(6) Unmetamorphosed limestone in contact with the quartz monsonite for about 500 feet at the southwestern border of the intrusion.

The extreme irregularities encountered in limestone contact metamorphism may be explained in several ways. No single factor can explain all the phenomena; but probably several have operated simultaneously. Some of these factors and their bearing on the problem at Rye Patch may be summarized as follows:

(1) Composition of the magma. Lindgren (1904, p. 520) states that at Clifton-Morenci there seems to be a direct relation between the contact-metamorphic effect and the amount of quartz in the igneous rock. The small size and the uniformity of the Rye Patch intrusion would rule out composition of the magma as a factor.

(2) Distance from the intrusion. All other things being equal, the intensity of the metamorphism should be greater nearer the intrusion. At Rye Patch, the distribution of the various metamorphic facies in the outer area may be ascribed to distance from the source of heat and emanations, but the inner area, while reflecting the influence of distance, requires an additional explanation for the less regular arrangement of metamorphic products.

The second belt of metamorphosed limestone, the outer area,—similar in its complex character to the inner area but showing well-defined zoning—suggests that an offshoot of the main intrusion lies not far beneath the surface, presumably more or less sill-like in its upper reaches at least (Fig. 11). Within this outer area, we find a higher grade of metamorphism in the north, decreasing gradually southward and westward (Fig. 10). In the north, silication is much more extensive, and the variety of contact minerals is greater. The marble zone is broader, while the unmetamorphosed remnants of limestone are fewer and smaller. In the south, conditions are quite

different; tremolite is the only common silicate mineral, and it is not abundant; the marble zone is narrow; and the unaltered remnants are frequent and large. The gradation from strong to weak metamorphism in the outer area can easily be accounted for by increasing distance from the source of heat and emanations; in other words, to the south the intrusion lies farther below the surface.

In the inner area, where tactite is encountered at the contact, light silicates and then marble succeed outward from the intrusion; where light silicate rock occurs next to the quartz monzonite, a marble zone follows; and where marble fringes the intrusion, it becomes finer-grained and contains fewer patches of silicates away from the igneous body.

(3) Structural features in the invaded rocks. Bedding planes afford easy passage for mineralizing solutions. Inclined strata, particularly, may aid their upward migration (Barrell, 1902, p. 394). At Rye Patch, bedding control of the extent of metamorphism is evinced in at least three ways:—(a) the widening of the inner area of metamorphism along the strike; (b) the relation of the outer contact area to the dip and strike; and (c) the narrowness of the aureole at the eastern contact, believed due to the fact that the strata conformably underlie the intrusion at this point (Fig. 11).

The influence of fractures on contact metamorphism has been discussed by Hess and Larsen (1920) but does not apply to Rye Patch because of the absence of any extensive fractures traversing the invaded rocks.

Variation in porosity of different beds may be important in aiding selective replacement. Lindgren (1904, p. 520) states that coarser-grained (and impure) limestones are more susceptible to metamorphism than compact (and pure) limestones. At Rye Patch, porosity may have been a factor guiding the silicating solutions along the layers now composed of calc-hornfels, and possibly along replaced beds.

(4) Composition of the invaded rock. Impure limestones are most susceptible to alteration, igneous rocks are least. In the Rye Patch area, however, the country rock as a whole is uniformly pure limestone. The manner in which the inner contact area cuts across a considerable thickness of these similar beds indicates that in the immediate vicinity of the magma metamorphic effects were due largely to emanations from it and not to differences inherent in the intruded rocks. An extended analysis of the question of original differences in country rock versus additions from the magma was made by Uglow (1913). Similar beds can be traced along their strike into different products of metamorphism. Obviously, the larger distribution of contact-metamorphic effects did not depend upon composition of the country rock.

One outstanding example of selective replacement due to differences in composition, however, seems to have been the three layers of calc-hornfels near the edges of the unmetamorphosed limestone separating the inner and outer areas (Fig. 10). These, probably, were originally more silty layers, similar to those occasionally encountered in the limestone outside the sphere of contact metamorphism, and thus readily underwent complete metamorphism, aided no doubt by greater porosity and favorable attitude, while the surrounding pure, more compact limestones remained unchanged.

A similar feature occurs nearer the intrusion on a very small scale. Here the original differences in composition are harder to understand, for the silicated beds

can be traced along the strike into limestone apparently similar to that of the adjacent unaltered layers. However, even though mineralogical composition and porosity appear the same, there must have been enough difference to render these beds more soluble, so that emanations chose these layers in preference to their neighbors. Boutwell (1905, p. 193) has advanced difference in solubility as an explanation of selective

FIGURE 16.—*Tourmaline-bearing pegmatite*

Showing tourmaline (To) replacing orthoclase (K), plagioclase (P), and microcline (M); apatite (A). Diagrammatic sketch from microscopic field. × 15.

replacement at Bingham, Utah. An alternative explanation, less reasonable in view of the small scale of the feature, would be local absence of emanations.

(5) Variations in heat and emanations at the margins of the intrusion. The Rye Patch intrusion is believed to be an offshoot of a larger buried intrusive, in fact, essentially a cupola, and probably as a whole differed from its parent body somewhat in temperature and escaping volatiles. Within its own comparatively small extent, however, such variations would be of a smaller order of magnitude. Nevertheless, by elimination of other determinable factors, these must account for the differences in degree of metamorphism along the actual contact. The reasons for such variations are not clear.

LATER PHASES OF THE INTRUSION

GENERAL STATEMENT

The petrography and distribution of the aplite phase have already been mentioned, and its significance is discussed later.

PEGMATITIC PHASE

The pegmatitic phase of mineralization is marked by the development of pegmatites and a small amount of tourmaline. The pegmatites and associated apatite and sphene have already been discussed. The tourmaline occurs in veinlets in the northern margin of the quartz monzonite and in the aplites and pegmatites, where it replaces orthoclase and, less often, plagioclase (Fig. 16).

Concerning the volatile emanations given off during this phase of mineralization, it would seem that the halogens were somewhat lacking, although no doubt a little fluorine and possibly a trace of chlorine were present, and a limited amount of boron.

HYDROTHERMAL PHASE

General considerations.—The hydrothermal phase is represented by silicification, by the prominent quartz veins which cut the major rock units, by tungsten and sulphide mineralization, and by carbonate veins.

Silicification.—Silicified areas are irregularly distributed throughout the limestone, which they resemble so closely that they are difficult to distinguish in the field. The most prominent example of silicification is at the faulted western edge of the intrusion, where specimens of the quartz monzonite from the mine show replacement of almost all the original constituents by quartz. A few remnant grains, chiefly zircon and biotite, indicate the nature of the original rock. The quartz shows typical secondary structures, such as feather and mosaic structure. Some later disturbance, probably the faulting, has sheared and bent the quartz. Silicification has also occurred in the outer contact area accompanied by introduction of orthoclase and sulphides. In this location, the silicified zone passes upward into tourmaline-bearing quartz veins (Fig. 12).

Quartz veins.—Quartz veins are common in the area, occurring in the quartz monzonite, in the tactite of the outer area, and in the limestone. They consist largely of massive white to grayish-white quartz. Sulphides are carried in the veins cutting the quartz monzonite, while conspicuous needles of tourmaline are found in the two large quartz veins traversing the tactite of the outer zone (Fig. 17). In the hand specimen these needles are dark brown and under the microscope, greenish brown. They are often replaced by calcite.

Within the limestone the quartz veins sometimes parallel the bedding. In the northwestern part of the area, a prominent bedding vein carries scheelite associated with calcite, but no tourmaline. This vein is associated with aplitic material which has invaded the limestone.

Sulphide mineralization.—The sulphides accompanying the silicification in the outer zone and in the limestone are arsenopyrite, pyrite, pyrrhotite, sphalerite, some galena, and tetrahedrite. Pyrite is the most abundant, forming euhedral grains especially in the replaced limestone (Fig. 18). The inner contact zone is almost devoid of pyrite and contains none of the other sulphides.

The quartz veins within the monzonite carry sulphides and are being developed in the Rye Patch Agnes mine in the northern part of the intrusion. Mineral relations are better exposed in the workings of the mine. Openings have been made on three levels; the upper two had reached the silver-bearing veins, while the lower one, starting some distance to the west, had not yet done so when the writer was last in the field. Most of the workings are in the intrusion proper, some are actually on the quartz veins, and some pass into the adjacent limestone.

The veins which carry the economic minerals are of white massive quartz, which shows abundant evidence of later crushing. In general, the walls of the veins are clearly marked, although in several instances silicification of the quartz monzonite on

both walls tends to destroy this demarcation. The veins dip steeply and the ore-bearing ones strike east-west.

Greisenization and a slight amount of tourmalinization have occurred in the vein walls. Molybdenite, pyrite, chalcopyrite, sphalerite, galena (silver-bearing), and tetrahedrite represent the complete suite of ore minerals.

FIGURE 17.—*Tourmaline in quartz vein from outer contact zone*

Tourmaline, To; quartz, Q; calcite, C. Diagrammatic sketch from microscopic field. × 15.

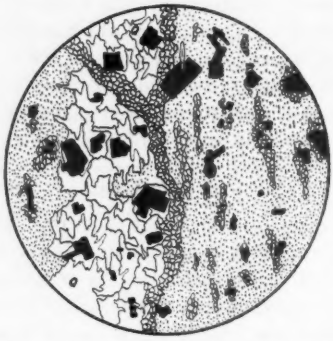


FIGURE 18.—*Silicified and pyritized limestone*

Showing various stages of quartz (Q) introduction. Pyrite represented by black grains. Diagrammatic sketch from microscopic field. × 15.

Deposition of some of the early minerals was followed closely by shattering; thus, pyrite and sphalerite are noticeably fractured, and the pyrite in some instances has been so ground up that it consists of a linear arrangement of tiny fragments.

The paragenesis of the ore minerals appears to follow Lindgren's "normal" order. The ore mineralization period was probably closely connected in time with the pyritization in the east, in the outer contact zone.

A slight amount of leaching has left remnant cavities corresponding in form to pyrite crystals.

The occurrence of molybdenite, generally regarded as a higher-temperature mineral, does not necessarily mean a hypothermal origin for the veins. Vanderwilt (1933, p. 571–572) describes molybdenite-bearing quartz veins associated with sulphides, a condition similar to that found in the Rye Patch Agnes mine, and concludes that this type is "probably formed under conditions more closely approaching those of the mesothermal." The well-defined vein walls support the mesothermal origin for the Rye Patch veins.

Tungsten mineralization.—In the limestone almost half a mile north of the intrusion are scheelite-bearing quartz veins of the bedding and fissure types, associated with the numerous aplitic injections. Four claims covering the known occurrence of the ore are situated on the ridge just north of Panther Canyon—constituting the Panther Canyon prospect. One large bedding vein is exposed in a trench which extends for 320 feet along the steep canyon wall. Three other small bedding veins have been exposed in the workings.

These tungsten veins are associated with the silicified and silicated areas bordering the aplite and camptonite dikes. The extent of such metamorphism is negligible around the camptonite but is significant near the aplites. The brownish, fine-grained aplites, whose outcrops are sometimes lenticular, are somewhat similar to those of the Oreana area (Kerr, 1938). Certain limestone beds change color along

FIGURE 19.—*Silicified lens in limestone*

Near the Panther Canyon prospect. Quartz, Q; orthoclase, O; actinolite, A; epidote, E; limonite, L. Diagrammatic sketch from microscopic field. × 15.

the strike and resemble the aplite intrusions. Thin-section examination shows that these beds are progressively silicified; in addition, orthoclase and innumerable sheaves of actinolite have been produced (Fig. 19). Further silicification away from the brownish layers has produced numerous nodules of white chert, accompanied by fibrous actinolite. The relation between the quartz veins and the altered zones is indicated by the occurrence of quartz veins in the center of the zones and their occasional gradation into each other.

The vein quartz is massive, white, frequently crumbling with ease in the hand specimen, and contains occasional vugs lined with quartz crystals. Quartz, scheelite, and calcite are the only vein minerals. In contrast to the quartz in the outer contact zone, tourmaline is exceedingly rare. Quartz was the earliest mineral to be deposited, followed closely by scheelite. Calcite transects both the quartz and the scheelite.

A trace of scheelite was found in an aplite dike within the quartz monzonite, and further traces were found in the epidote-garnet rock on the southern contact of the intrusion. When the locations of the tungsten occurrences are mapped they show a decided linear trend, coinciding with the axis of the arch in the sediments, suggesting that the localization was controlled by this structure (Fig. 20).

Aplites are abundant where tungsten is prominent and appear to have afforded passage for the tungsten-bearing solutions. The association of scheelite deposits with aplites has been described at Oreana, Nevada (Kerr, 1938), and in the Federated Malay States (Willbourn and Ingham, 1933), but the genetic relationship between the two has not been established. Recently Kerr (1940, p. 208) stated: "Aplite and

pegmatite dikes or quartz veins favor concentration of tungsten evidently as conduits from the magmatic sources. The conduits frequently contain traces, but rarely concentrations of tungsten minerals."

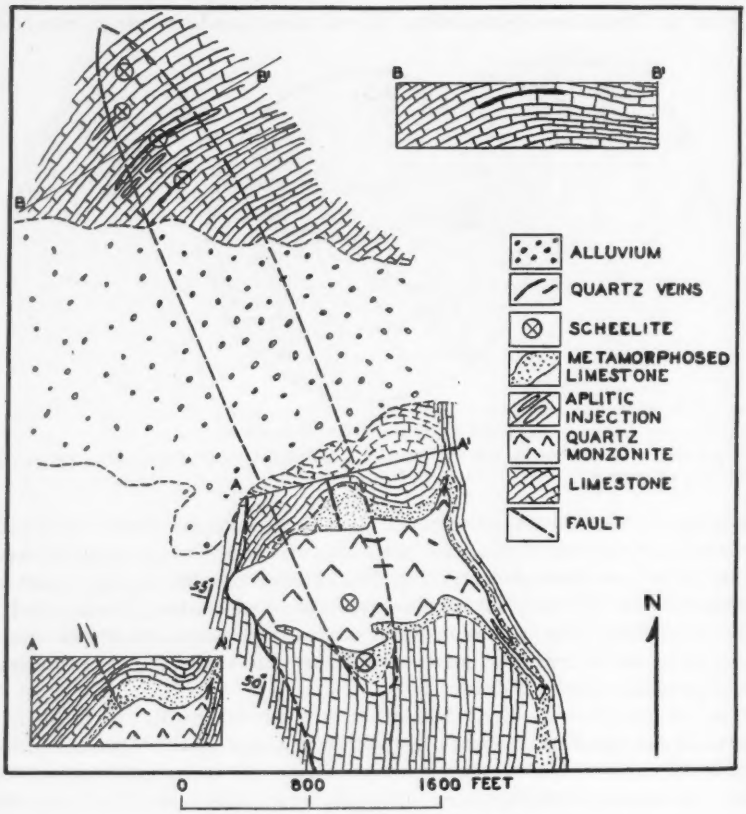


FIGURE 20.—*Plan of tungsten occurrences*
Showing their relation to the arch in the sediments, which is outlined by dashed lines

The scheelite found at the Panther Canyon prospect is evidently hydrothermal, differing from the deposit at Oreana, where the scheelite is associated with pegmatites. According to Butler (1927, p. 238) and Finlayson (1910, p. 26) scheelite is not necessarily formed only at high temperatures but continues to be deposited, probably in decreasing amounts, at lower and lower temperatures. A similar occurrence of scheelite has been described by Hulin (1925, p. 77) at Atolia, California.

The scheelite was formed when most volatiles except water were either rare or absent, as suggested by the absence of any considerable mineralization in the veins

proper. In the isolated instances of scheelite found in the aplite and in the contact rock, there is no evidence of hydrothermal activity; this scheelite may have been formed contemporaneously with the aplite and the contact metamorphism, respectively.

CONCLUSIONS

(1) Contact metamorphism at Rye Patch, Nevada, involved considerable change in composition, mainly the addition of silica, alumina, and iron oxide, and subtraction of carbon dioxide.

(2) No appreciable volume change occurred.

(3) The contact-metamorphic changes depended mainly on the magmatic emanations, since the original sediments were uniformly pure limestones, except for three horizons where they may have been silty.

(4) The distribution of metamorphic effects is believed to be due primarily to distance from the intrusion, modified locally by (a) bedding of the invaded strata, (b) variations in composition, porosity, and solubility of the original limestone, and (c) variations in heat and emanations at the margins of the intrusion.

(5) The outer contact area is thought to be due to another tongue of the intrusion which has not yet been uncovered by erosion.

(6) In its upper reaches, the intrusion is sill-like and has pried apart the limestone beds.

(7) The arching of the sediments is believed to indicate a northward extension of the intrusion, parallel to the strike.

(8) The diopside and andradite are the oldest contact-metamorphic minerals; andradite was succeeded at some stage by grossularite and was in part altered to epidote. Some diopside was altered to tremolite. The exact relations of the idocrase, tremolite, and wollastonite are not so clear.

(9) The distribution of the tungsten mineralization and aplite dikes in a linear belt coinciding with this arch suggests structural control.

(10) The scheelite veins are of low-temperature hydrothermal origin.

(11) The aplites associated with the scheelite-bearing quartz veins probably afforded passage to the tungsten-bearing solutions.

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Manuscript Received by the Secretary of the Society, July 7, 1943.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 55, PP. 951-992, 5 PLS., 5 FIGS. AUGUST 1944

MORRISON FORMATION AND RELATED DEPOSITS IN AND ADJACENT TO THE COLORADO PLATEAU

BY WILLIAM LEE STOKES

CONTENTS

	Page
Abstract	952
Introduction	952
Aims and methods of investigation	952
Acknowledgments	953
Statement of the problem	953
General considerations	953
Type section	954
Definition of Morrison	956
Summary of previous investigations and review of nomenclature	957
Description of lithologic units involved	958
Todilto limestone and related deposits	958
Bluff sandstone and equivalents	959
Pony Express limestone, Bilk Creek sandstone, and Wanakah marl	960
Junction Creek sandstone	961
Salt Wash sandstone, Recapture shale, and Westwater Canyon sandstone members of the Morrison formation	962
Brushy Basin shale	964
Buckhorn conglomerate and equivalents	965
Cedar Mountain shale	966
Post-McElmo beds	967
Dakota formation	968
Gannett group	968
Beckwith formation	969
Currant Peak section	970
Kelvin conglomerate	970
Paleogeography and lithogenesis	971
Structural and stratigraphic setting	971
Jurassic marine transgressions	972
Terrestrial sedimentation	974
Buckhorn conglomerate	976
Source of Buckhorn conglomerate	978
Final phases of terrestrial sedimentation	981
Problems of correlation and nomenclature	981
General considerations	981
Todilto formation	984
Bluff sandstone	985
Pony Express limestone, Bilk Creek sandstone, and Wanakah marl	985
Salt Wash sandstone, Recapture shale, and Westwater Canyon sandstone	986
Brushy Basin shale	987
Cedar Mountain group	987
Other correlations	989
References cited	990

ILLUSTRATIONS

Figure Page
1. Type section of the Morrison formation 955
2. Map showing approximate limits of distribution of certain lithologic units in adjacent parts of Utah, Colorado, Arizona, and New Mexico 962
3. Generalized sedimentary cycle for the Colorado Plateau 971
4. Development of desert armor 977
5. Restored sections of late Jurassic and early Cretaceous sediments 982

Plate Facing page
1. Rock exposures in the Colorado Plateau 958
2. Pre-Morrison Jurassic sediments 959
3. Typical exposures of members of Morrison formation 966
4. Cedar Mountain group 967
5. Generalized outcrop map of Morrison formation and related deposits in portions of Utah, Colorado, New Mexico, Arizona, Wyoming, and Idaho 968

ABSTRACT

The Morrison formation in and adjacent to the Colorado Plateau currently includes diverse lithic units, many of which cannot properly be included if the limitations of the type section and relationships to other formations are considered. The Todilto limestone, Bluff sandstone, Wanakah marl, Pony Express limestone, and Bilk Creek sandstone can be correlated with the San Rafael group and dated as Upper Jurassic by the marine beds in the group. The Salt Wash sandstone, Brushy Basin shale, Recapture Creek sandstone, and Westwater Creek sandstone are considered equivalent to the type Morrison and have yielded vertebrate remains and are almost certainly Jurassic. Succeeding these are two new formations, the Buckhorn conglomerate and Cedar Mountain shale, which have yielded no fossils but are tentatively classed as Lower Cretaceous, mainly by analogy with similar deposits in adjacent areas.

Lithology, distribution, and paleogeography of all units are discussed, and changes in nomenclature and correlation are recommended.

INTRODUCTION

AIMS AND METHODS OF INVESTIGATION

The chief objectives of this study of the Morrison formation are the discrimination and tracing of the major lithic components in and adjacent to the Colorado Plateau, a consideration of the relationships of the formation to underlying and overlying beds, an analysis of the paleontologic and stratigraphic evidence for current age assignments of the beds involved, an interpretation of the paleogeography of the late Jurassic and early Cretaceous, and suggestions for revisions in nomenclature and correlation.

The field work was primarily the examination of as many outcrops in the chosen area as time allowed. Type localities were visited, and most of the sections shown on the outcrop map (Pl. 5) were measured in detail.

Examination of sections over a wider area than has been usually involved in one report has clarified some of the stratigraphic problems, and the resulting correlations may aid in the evaluation of fossil material found in the area.

The summer of 1939 was spent in detailed work in the San Rafael Swell, Emery County, Utah, where a quarry was opened in the dinosaur beds. The 1940 season was devoted to field work in parts of Utah, Colorado, Wyoming, and Idaho.

Identification of fossil material was entrusted to various specialists, while the lithologic and library studies were made during the winters of 1939 and 1940.

Plate 5 shows the area covered, the location of sections measured and examined, and the generalized distribution of outcrops of the Morrison and related deposits. It has been compiled mainly from publications of the United States Geological Survey; minor details have been added by the author.

ACKNOWLEDGMENTS

Owing to several generous grants from the Scott Fund of Princeton University this investigation was carried on over a wider area than would have been otherwise possible. The author wishes to express his appreciation to the custodian of this fund, Dr. G. L. Jepsen, for his liberal support of this project.

For the identification of fossil material thanks are due Messrs. Carl O. Dunbar, R. S. Bassler, J. B. Reeside, Jr., and E. D. McKee.

Critical and constructive aid has been rendered by members of the Department of Geology, Princeton University, especially Erling Dorf, G. L. Jepsen, and J. Brookes Knight. To these and other advisors who have contributed in many ways the writer extends his appreciation.

For assistance in the field the writer wishes to acknowledge the generosity of his father, W. P. Stokes, who supplied means of transportation over the area covered. The author is indebted to his brother, L. Grant Stokes, for field assistance and especially to his wife, Betty C. Stokes, for her part in the field work and also the final preparation of the manuscript.

STATEMENT OF THE PROBLEM

GENERAL CONSIDERATIONS

The Morrison problem has become one of the classics of American geology and has engaged the attention of stratigraphers and paleontologists intermittently for over 70 years. The age of the formation has been the chief point of dispute, and opinion has shifted from Jurassic to Cretaceous and back again. The uncertainty has not been entirely due to lack of fossils, for the Morrison is rich in vertebrates and also yields intertebrates and plant remains. The dinosaur fauna is the most varied and distinctive of any known, but its value in correlation is limited. Accumulated evidence suggests that the fauna is Jurassic, but definite unequivocal correlation with European type sections is lacking.

Owing to intensive study of the reptilian and mammalian faunas the paleontologic aspect of the age problem has been more thoroughly investigated than the stratigraphic. In fact, a discrimination and tracing of different lithic units and the study of the relationships of underlying and overlying beds have been almost entirely neglected.

In the Rocky Mountains the interval between the last adequate marine faunas of Jurassic age (Sundance) and the first Cretaceous faunas (Washita in some areas, Colorado in others) is long, and sedimentation of some sort probably continued intermittently at various places in the Morrison area. The assumption that all sedimentation was Jurassic and all erosion Lower Cretaceous over the entire area demands more proof than now exists. The term Morrison has been applied to strata covering about 350,000 square miles, includes diverse lithic units, and evidently has become a

convenient "waste-basket" where terrestrial beds of questionable age may be disposed of with little regard to the limitations imposed by type sections and the fossil evidence. No doubt, a great many of the conflicting paleontological opinions are due to indiscriminate collecting from horizons which probably bridge the Cretaceous-Jurassic boundary. No additional paleontologic evidence has been found by the author to disprove the current concepts of Jurassic age for those portions of the Morrison within the limits set by the type section and from which adequate faunas have been obtained. A comparison of the Morrison faunas with those from deposits of comparable age in widely separated areas has been made by several competent authorities (Schuchert, 1918; Simpson, 1926). However, stratigraphic analysis has shown that a considerable mass of sediments currently included in the Morrison can be traced into older well-dated fossiliferous formations. Other associated beds are evidently younger than true Morrison but are for the most part unfossiliferous and impossible to date with certainty.

Correlation of terrestrial deposits like the Morrison presents peculiar difficulties. Fossils of well-established age are practically absent, and faunas are useful in a general way only. Identical vertebrate types are found in no other deposits.

The expense and labor involved in collecting, preparing, and studying dinosaur remains proved a serious deterrent to their use as guide fossils. Moreover when most Jurassic dinosaurs were discovered little attention was paid to details of stratigraphy, and the original sites of many specimens are unknown. In contrast with the Mesozoic rocks of the Atlantic seaboard those of the Colorado Plateau are singularly lacking in mineral suites suitable for correlation. Stratigraphic sequence has proved to be unreliable in correlation, as beds identical in sequence of lithic types are by no means necessarily contemporaneous. The repetition of thick, cross-bedded sandstones, thin-bedded, red shales, and thin layers of dense limestone is common in the Colorado Plateau. The difficulties of correlation are in a measure compensated for by such favorable factors as lack of structural complications and excellent exposures.

TYPE SECTION

The type locality of the Morrison formation is at the town of Morrison, Colorado, and the section there is shown in Figure 1, taken from Lee (1927, Pl. 1, col. 4). The original description contains no detailed stratigraphic section, but the upper and lower limits as chosen by Eldridge are adequately stated in the type description, excerpts from which follow:

> "Throughout the Denver field and for much of the distance along the eastern base of the Rocky Mountains in Colorado the Jura is essentially a formation of fresh-water marls, of an average thickness of about 200 feet. Its upper limit is sharply defined by the Dakota sandstone, while the brown and pink sandstone closing the Trias as clearly marks its lower limit. To this formation has been assigned the name 'Morrison,' from the town near which it is typically developed.
>
> "The marls are green, drab, or gray, and carry in the lower two-thirds numerous lenticular bodies of limestone of a characteristic drab color and a texture compact and even throughout. . . . The clays of the lower two-thirds of the Jura are remarkable for their reptilian remains, and from the predominating form have been designated 'Atlantosaurus clays.'
>
> "The upper third of the Jura is generally a succession of sandstones and marls, of which the former predominate. . . . The most important sandstone occurs just above the Atlantosaurus clays, is very persistent, and from contained Saurian remains has been called the Saurian sandstone. It varies in thickness between 5 and 35 feet, and in its distance below the Dakota from 10 to 125 feet, although more generally from 50 to 80 feet. . . . At the base is generally a conglomerate, of a maximum thickness of 8 feet, in which the pebbles so closely resemble those of the Dakota that, but for a slight

admixture of red jasper and the characteristic brown dots, the two layers could with difficulty be distinguished from each other. The shales overlying this sandstone are similar to those comprising the bulk of the Jura, but carry through them a number of minor sandstones and occasionally one or two strata of limestone." (Eldridge, 1896.)

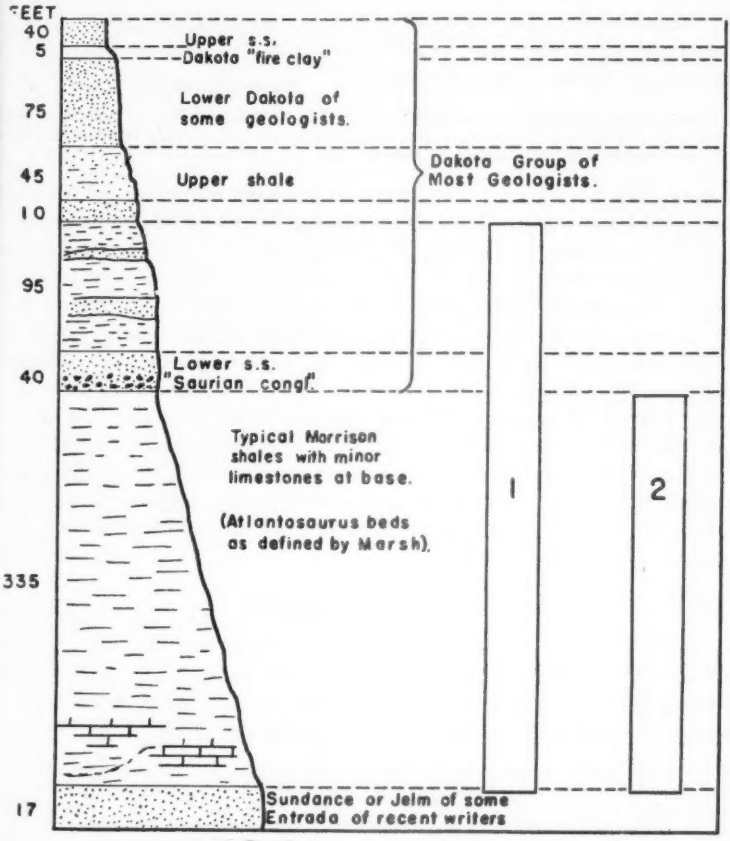


FIGURE 1.—*Type section of the Morrison formation*

Columnar section at left indicates lithic units present, blank section no. 1 at right indicates type section of Morrison as proposed by Eldridge, blank section no. 2 indicates type as now restricted. Section from W. T. Lee (1927, Pl. 1, col. 4.)

This definition of the type section was unquestioned until Knowlton (1920) described certain dicotyledonous plant remains collected by W. T. Lee "from the type section of the Morrison formation at Morrison, Colorado, occurring about 15 feet below the top of the formation." In summarizing his observations, Knowlton reports that this flora:

"finds its closest affinity with the so-called Dakota flora of the Denver Basin, a flora that is known to come in whole or in part from what is classed as the Purgatoire formation, and not from the Dakota as at present delimited. . . . The suggested classification makes Purgatoire include the plant-bearing part of the original Morrison, and makes it all basal Upper Cretaceous." (Knowlton, 1920, p. 193.)

This discovery indicates that the controversies over the age of the Morrison originated in the very nature of the type section, and very possibly if Eldridge had known of the flora just mentioned he would have restricted the Morrison to the Jurassic portion of the section.

W. T. Lee advocated a still more extensive revision of the type section. He removed the upper shale unit and the underlying "Saurian conglomerate" and placed it in the Dakota group. He says:

> "No obvious break was found in the section between the plant horizon and the base of the Saurian conglomerate. If No. 4 (the shale) is referred to Dakota on the basis of plant evidence, it will carry No. 5 (the conglomerate) with it." (Lee, 1920, p. 185.)

The lower limy portion of the Morrison was also split off by Lee on the basis of supposed Sundance fossils. The presence of these fossils had been reported by Hayden in 1873 and again by Lee in 1927 (identification by J. B. Reeside, Jr.); other writers have accepted these records, but few were able to find additional satisfactory remains. Reeside (1931) reported that a re-examination of the fossil evidence showed that the supposed Sundance fossils were in reality typical Morrison fresh-water mollusks and *Chara*-like algae, the latter having been mistaken for *Pentacrinus astericsus*. This new evidence invalidates Lee's revision of the lower part of the type section, and for the time being at least this lower part should be returned to its original status as part of the Morrison. This places the lower limit at the top of a series of red sediments, "ending in a persistent bank of pink and brown sandstone" (Eldridge, 1896, p. 20). This sandstone has lately been correlated with the Entrada (Heaton, 1939) and has a patchy development over most of the area along the Front Range.

DEFINITION OF MORRISON

In defining the Morrison formation the limitations of the type section should be borne in mind, as well as the reasons for the present wide application of the term in the Rocky Mountain region. The author believes that an adequate definition already exists in the excellent paper of Baker, Dane, and Reeside (1936, p. 31), who state:

> "The writers wish to emphasize the fact that in correlating the post-San Rafael beds—they have included in the Morrison rocks that differ much from the more typical variegated shale facies—that is, fairly thick massive limestones and thick massive, sandstones. Yet each of these divergent lithologic facies can be found in lesser development in areas where there can be little doubt of its Morrison age. Some of the units have received individual names. It seems not only possible but probable that in various regions other lithologic units in this mass of sediments will eventually be discriminated and traced with sufficient accuracy to justify the application of local member names. Such discrimination and naming is eminently desirable, but in the present state of knowledge and in view of the characteristic variability and irregularity manifested where the formation has been studied in great detail, it seems legitimate to include under the name Morrison all the Jurassic continental sediments deposited subsequent to the deposition of the San Rafael group."

Thus Morrison sedimentation is delimited by two events: (1) the withdrawal of the Jurassic seas in and marginal to which the members of the San Rafael group were deposited, and (2) the end of the Jurassic period. The withdrawal of the Logan sea must be interpreted broadly and only those beds deposited after the final disappearance of the sea from the region east of the Mesocordilleran geanticline can be accepted as Morrison.

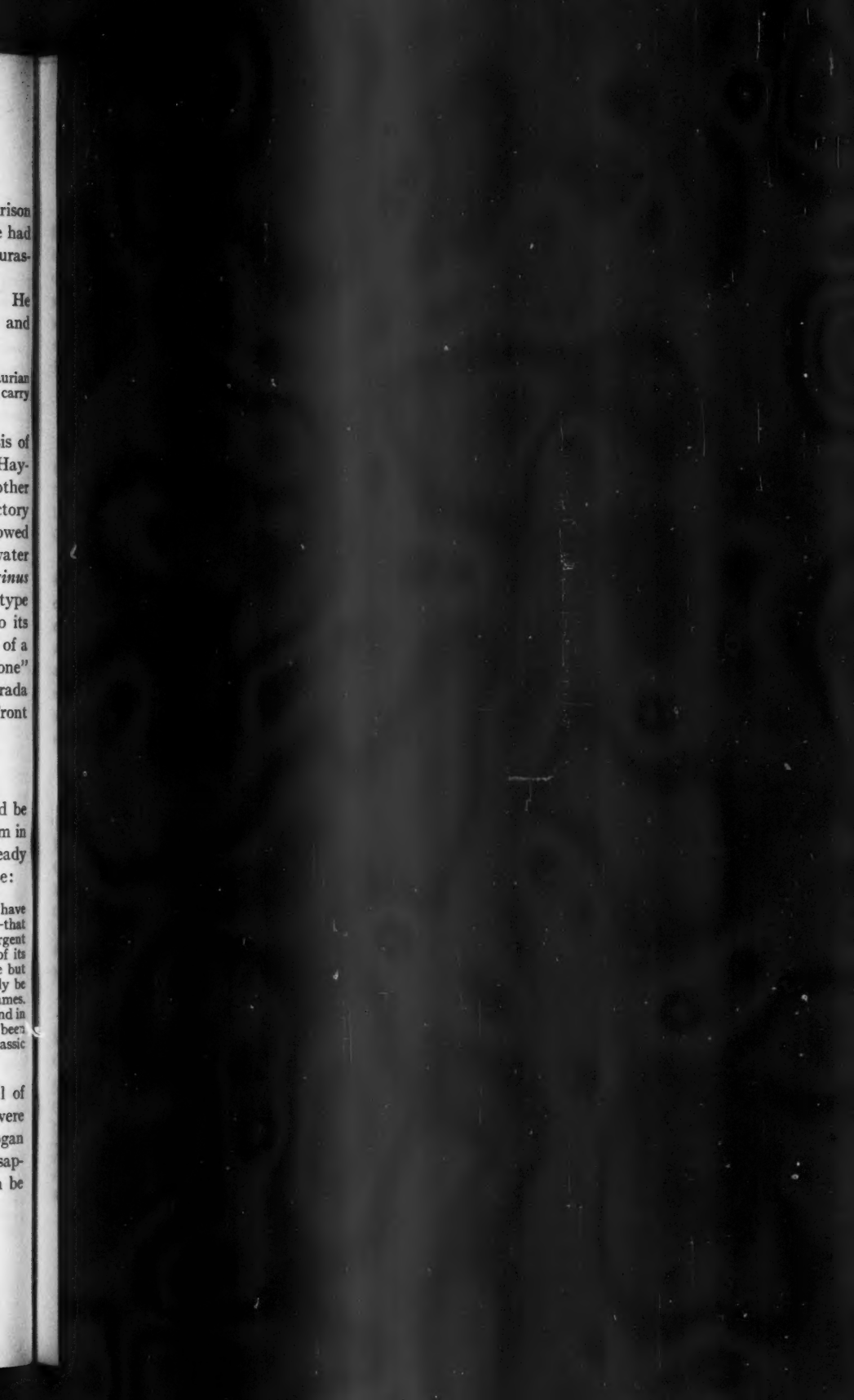


TABLE 1.—

COLORADO P

G. K. GILBERT — HENRY MOUNTAINS — 1880		WHITMAN CROSS ET AL, — SOUTHWESTERN COLORADO — 1899	WHITMAN CROSS — WESTERN COLORADO AND EASTERN UTAH — 1907	H. E. GREGORY — NAVAJO COUNTRY — 1917	W. B. EMERY — GREEN RIVER DESERT — 1918	R. C. COFFIN — SOUTHWESTERN COLORADO — 1921	J. GILLUL — SAN S
A	HENRY'S FORK GROUP	DAKOTA FORMATION (locally absent)	CRETACEOUS	DAKOTA FORMATION	DAKOTA FORMATION	DAKOTA SANDSTONE	DAKOTA
						POST McELMO	MORRISON FORMATION
B		McELMO FORMATION	McELMO FORMATION	McELMO FORMATION	McELMO FORMATION	McELMO FORMATION	
C							SAN RAFAEL GROUP
		LA PLATA GROUP — UPPER			NAVAJO SANDSTONE (= present Entrada sandstone)	LA PLATA GROUP — UPPER	
	FLAMING GORGE GROUP	LA PLATA GROUP — MIDDLE	LA PLATA SANDSTONE	NAVAJO SANDSTONE	TODILTO FORMATION (= present Carmel formation)	LA PLATA GROUP — MIDDLE	
		LA PLATA GROUP — LOWER		TODILTO FORMATION			
		TRIASSIC		WINGATE SANDSTONE	WINGATE SANDSTONE (= present Navajo sandstone)	LA PLATA GROUP — LOWER	

TABLE 1.—*Evolution of nomenclature for Jurassic and certain Cretaceous rocks of the Colorado Plateau and adjacent areas*
(Not intended to show exact horizontal correlation of lithologic units or time intervals)

PLATEAU

J. GILLULY & J.B. REESIDE, JR. 1928 — SAN RAFAEL SWELL	A. A. BAKER 1933 — MOAB AREA	H. E. GREGORY 1938 — SAN JUAN COUNTRY UTAH	M.I. GOLDMAN AND A.C. SPENCER 1941 — SAN JUAN MOUNTAINS	THIS PAPER — GENERALIZED FOR COLORADO PLATEAU
DAKOTA (?) SANDSTONE	DAKOTA (?) SANDSTONE	DAKOTA (?) SANDSTONE	UPPER PART OF MORRISON NOT STUDIED	DAKOTA (?) SANDSTONE
				CEDAR MOUNTAIN FORMATION (west-central part of area)
				BUCKHORN CONGLOMERATE (west-central part of area)
MORRISON FORMATION	MORRISON FORMATION	MORRISON FORMATION: BRUSHY BASIN SHALE MEMBER	MORRISON FORMATION: JUNCTION CREEK SANDSTONE (locally absent)	MORRISON FORMATION: BRUSHY BASIN SHALE MEMBER (entire area)
		WESTWATER CANYON SHALE MEMBER	WANAKAH MARL MEMBER	WESTWATER CANYON SHALE MEMBER
SALT WASH SANDSTONE MEMBER	SALT WASH SANDSTONE MEMBER	RECAPTURE CREEK SHALE MEMBER	BILK CREEK SANDSTONE MEMBER	RECAPTURE CREEK SHALE MEMBER
		BLUFF SANDSTONE MEMBER	PONY EXPRESS LIMESTONE MEMBER	SALT WASH SANDSTONE MEMBER (south, east, and central parts of area)
SAN RAFAEL GROUP: SUMMERVILLE FORMATION	SAN RAFAEL GROUP: SUMMERVILLE FORMATION			SAN RAFAEL GROUP: SUMMERVILLE-CURTIS (absent in southern parts of Colorado Plateau)
CURTIS FORMATION	CURTIS FORMATION / MOAB SANDSTONE MEMBER			BLUFF SANDSTONE (equivalent to part of Entrada and perhaps Curtis)
ENTRADA SANDSTONE	ENTRADA SANDSTONE	SAN RAFAEL GROUP UNDIFFERIENTIATED	ENTRADA SANDSTONE	TODILTO FORMATION (probably equivalent to part of Entrada and all of Carmel)
CARMEL FORMATION	CARMEL FORMATION			
NAVAJO SANDSTONE	NAVAJO SANDSTONE	GLEN CANYON GROUP	NOT STUDIED	GLEN CANYON GROUP

SOUTHWESTERN WYOMING AND ADJACENT AREAS

J.W. POWELL 1876 — EASTERN UINTA MOUNTAINS	CLARENCE KING 1878 — 40TH PARALLEL SURVEY	A. C. VEATCH 1907 — SOUTHWESTERN WYOMING	G. R. MANSFIELD AND R. V. ROUNDY 1927 — SOUTHEASTERN IDAHO	ROSS HEATON 1939 — JURASSIC OF ROCKY MOUNTAINS
		BEAR RIVER FORMATION	WAYAN GROUP	CRETACEOUS NOT STUDIED
HENRYS FORK GROUP	DAKOTA FORMATION			
	JURASSIC	BECKWITH FORMATION	GANNETT GROUP	MORRISON FORMATION
FLAMING GORGE			STUMP SANDSTONE	STUMP=CURTIS
			PREUSS FORMATION	PREUSS = ENTRADA
WHITE CLIFF GROUP		TWIN CREEK LIMESTONE	TWIN CREEK LIMESTONE	TWIN CREEK=CARMEL
				NUGGET SANDSTONE
		NUGGET SANDSTONE	NUGGET SANDSTONE	

The top of the Jurassic is not marked by a pronounced stratigraphic break, and fossil material is of little aid in delimiting the period in this area. However, between the last definite Jurassic fossils and the first Cretaceous fossils, so far adequately evaluated, a long period elapsed, involving some of the Jurassic and all the Lower and some of the Upper Cretaceous. The conditions prevailing during this time are obscure, and only by analogy with surrounding regions and by paleogeographic considerations has a usable line of demarcation for the top of the Jurassic, and hence the Morrison, been chosen.

SUMMARY OF PREVIOUS INVESTIGATIONS AND REVIEW OF NOMENCLATURE

Development of knowledge concerning the late Jurassic and early Cretaceous of the area here treated and the consequent refinements in nomenclature are outlined in Table 1. This summarizes the major contributions, but many minor works cannot be cited. For a more complete treatment of the nomenclature of the Jurassic of the Colorado Plateau Baker, Dane, and Reeside (1936) should be consulted.

Inasmuch as a thorough understanding of the Morrison problem demands the consideration of an unusually large number of overlying and underlying beds and of other associated formations, a brief review of terminology is included. For convenience the formation and group names are classified in four categories: (1) terms now abandoned or restricted in application; (2) terms established in the literature and accepted as valid by current investigators; (3) terms recently proposed but not yet accepted as valid and useful; and (4) terms proposed in the present paper. For additional information on the various units Wilmarth (1939) and the bibliography of this paper should be consulted.

Terms Now Restricted or Abandoned

Atlantosaurus beds—Marsh (1877), Jurassic, equivalent to lower part of Morrison as originally defined.

Beulah clays—Jenney (1897), U. Jurassic, equivalent to Morrison formation.

Como beds—Scott (1897), U. Jurassic, equivalent to Morrison formation.

Flaming Gorge group—Powell (1876), U. Jurassic, equivalent to Curtis and part of Morrison.

Gunnison formation—Eldridge (1894), U. Jurassic, equivalent to Morrison and Entrada (?).

La Plata group—Cross (1899), U. Jurassic, equivalent to lower Morrison, Summerville, Curtis, and Entrada.

Saurian conglomerate—Eldridge (1896), U. Jurassic, part of Morrison as originally defined.

Terms in Current Usage

Beckwith formation—Veatch (1907), U. Jurassic and Cretaceous (?).

Carmel formation—Gilluly and Reeside (1926), U. Jurassic.

Cloverly formation (or group)—Darton (1904), L. Cretaceous.

Curtis formation—Gilluly and Reeside (1926), U. Jurassic.

Dakota sandstone—Meek and Hayden (1862), U. Cretaceous. (The Dakota sandstone is recognized with certainty only east of the Front Range; for exposures of comparable age to the west the term Dakota (?) formation is used. Dakota group is used by some authors for areas in northern Colorado and parts of Wyoming.)

Entrada sandstone—Gilluly and Reeside (1926), U. Jurassic.

Fuson shale—Darton (1901), L. Cretaceous.
Gannett group—Mansfield and Roundy (1917), Cretaceous (?).
Inyan Kara group—Rubey (1930), L. Cretaceous.
Kelvin conglomerate—Mathews (1931), U. Cretaceous (?).
Lakota sandstone—Darton (1899), L. Cretaceous.
Morrison formation—Eldridge (1896), U. Jurassic.
Navajo sandstone—Gregory (1917), Jurassic.
Preuss sandstone—Mansfield and Roundy (1917), U. Jurassic.
Salt Wash sandstone member of Morrison—Lupton (1914), U. Jurassic.
San Rafael group—Reeside, Dobbin, Baker, and McKnight (1927), also Gilluly and Reeside (1928) U. Jurassic, includes Summerville, Curtis, Entrada, and Carmel formations.
Stump sandstone—Mansfield and Roundy (1917), U. Jurassic.
Summerville formation—Gilluly and Reeside (1926), U. Jurassic.
Sundance formation—Darton (1899), U. Jurassic.
Twin Creek limestone—Veatch (1907), U. Jurassic.
Wayan group—Mansfield and Roundy (1917), U. and L. Cretaceous (?).

TERMS RECENTLY PROPOSED

(All designate units of Upper Jurassic age)

Bilk Creek sandstone member of Morrison—Goldman and Spencer (1941).
Bluff sandstone member of Morrison—Gregory (1938).
Brushy Basin shale member of Morrison—Gregory (1938).
Junction Creek sandstone member of Morrison—Goldman and Spencer (1941).
Pony Express shale member of Morrison—Goldman and Spencer (1941).
Recapture Creek shale member of Morrison—Gregory (1938).
Wanakah shale member of Morrison—Goldman and Spencer (1941).

TERMS PROPOSED IN THIS PAPER

Buckhorn conglomerate—L. Cretaceous (?).
Cedar Mountain shale—L. Cretaceous (?). } Cedar Mountain group

DESCRIPTION OF LITHOLOGIC UNITS INVOLVED

TODILTO LIMESTONE AND RELATED DEPOSITS

The Todilto limestone was proposed as a formation name by Gregory (1917, p. 55) who designated Todilto Park, New Mexico, as the type locality. He published a section measured 12 miles west of the Carrizo Mountains, and Baker, Dane, and Reeside report outcrops as far north as Beclabito Dome, New Mexico (1936, p. 17). That these northern exposures are to be correlated with the type locality has been questioned by Goldman and Spencer (1941, p. 1761–2). However, as Baker, Dane, and Reeside consider the Todilto to be the base of the Morrison over wide areas in New Mexico and Arizona and as Goldman and Spencer correlate the thin higher limestone at Beclabito with their Pony Express limestone, consideration must be given to the tracing of these units into areas where the San Rafael group is present.

Gregory (1917, p. 55) describes the type Todilto as: "massive, dense, pure lime-

FIGURE 1. VIEW LOOKING DOWN SAN MIGUEL RIVER, MONTROSE COUNTY, COLORADO
Prominent light-colored stratum is Entrada sandstone. Slope above this and below lower tree-covered bench in left middle distance is Summerville equivalent. Salt Wash sandstone member of Morrison in right foreground. Hill at right consists mainly of Brushy Basin shale and is capped by Dakota (?). View from point near Dolores Camp.
(Photograph courtesy R. P. Fischer)

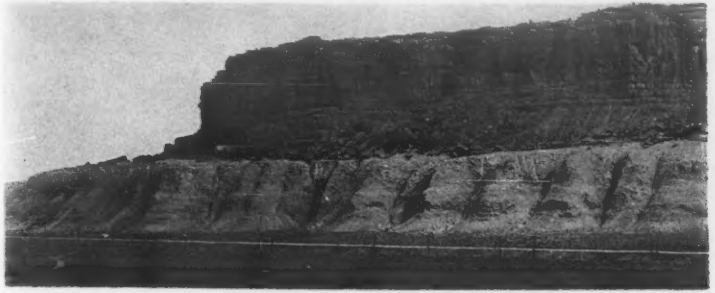


FIGURE 2. CLIFF ALONG THE ATCHISON, TOPEKA, & SANTA FE RAILWAY AT EL RITO, NEW MEXICO
Shows massive gypsum facies of Todilto formation overlain by thin-bedded shales and sandstone.
(Photograph by N. H. Darton, Courtesy U. S. Geol. Survey)

FIGURE 3. ENTRADA SANDSTONE REMNANT IN DRY VALLEY, UTAH
Lower dark, silty sandstone may be equivalent to part of Carmel.

FIGURE 1. EXPOSURES IN CANYON OF SAN MIGUEL RIVER NEAR VANADIUM, COLORADO
Dark stratum on steep cliff is Pony Express limestone, underlain by Entrada sandstone and overlain by Bilk Creek sandstone, both light-colored. Wanakah marl forms most of slope above the Bilk Creek.

FIGURE 2. "NAVAJO TWINS" AT BLUFF, UTAH
Entrada and Carmel sediments undifferentiated. Massive sandstone capping monuments is Bluff sandstone of some geologists.

FIGURE 3. JURASSIC ROCKS EXPOSED IN BIG FLATTOP BUTTE, GREEN RIVER DESERT, UTAH
E, Entrada sandstone; C, Curtis formation; S, Summerville formation; S W, Salt Wash member of the Morrison formation. Note similarity of bedding in three lower units. (Photograph by A. A. Baker, Courtesy U. S. Geol. Survey)

stone, blue gray on the surface, gray to pinkish on fresh fracture." He states also (p. 56):

"Along the San Juan southwest of Bluff, Utah a group of bedded sandstones, limestones and shales 30 to 50 feet in thickness separates the two massive sandstones of the La Plata group. From Marsh Pass northward and northwestward the middle part of the La Plata corresponding to the Todilto formation thickens and includes increasingly large amounts of shale."

Baker, Dane, and Reeside (1936, p. 55) state: "In places the Todilto limestone is intimately associated with or is replaced by a thick bed of gypsum, which would suggest aridity" (Pl. 1, fig. 2).

The writer has not seen the type locality nor traced the formation south of Red Rock, Arizona. However, the exposures around the Carrizo Mountains and north to Bluff, Utah, indicate, in the author's opinion, that the Todilto as previously recognized in those areas is well below the base of the Morrison.

The limestone thins northward from Red Rock and is replaced by increasing amounts of thin-bedded shale. The thin discontinuous patches of limestone north of Red Rock mark the approximate northern limit of the limestone facies. The shaly sandstone and crinkled beds which overlie and replace the limestone can be traced northward from the Carrizo Mountains by way of Red Mesa and Gothic Wash to Bluff, Utah, where they constitute the lower part of the Morrison of Baker, Dane, and Reeside and part of the San Rafael group of Gregory (Baker, Dane, and Reeside, 1936, p. 15, 21; Gregory, 1938, p. 57–60).

Dense, unfossiliferous limestones similar to the Todilto are present within the Wingate, between the Wingate and Navajo, within the Navajo, and above the Entrada, and although these local lenses are generally thinner than the type Todilto they are confusing.

The Todilto has yielded no fossils, except dinosaur tracks found by Gregory and reported by Lull as "not older than Triassic" (Gregory, 1917, p. 56).

The thick gypsum beds, crinkled thin-bedded red shales, and dense limestones are difficult to reconcile with more northern exposures of the Morrison and especially the type section but are logically associated with the marine beds of the Carmel formation and playa lake beds of the Entrada.

BLUFF SANDSTONE AND EQUIVALENTS

The term "Bluff sandstone" appears several times in the literature before 1938 but was not formally used until Gregory applied it to what he considered to be the lower member of the Morrison (1938, p. 58). The name is derived from characteristic exposures at the town of Bluff, Utah, where the unit constitutes the most striking topographic feature on both sides of the San Juan River (Pl. 2, fig. 2).

Baker, Dane, and Reeside (1936, p. 15) state:

"Above the San Rafael group at both Kayenta and Bluff are thin and uniformly bedded red and gray sandy shale and sandstone. This unit has suffered deformation much like that of the red bed facies of the Carmel and largely on that account has been previously correlated with it. The overlying gray, cliff-forming sandstone, known at Bluff as the "Bluff sandstone" has been correlated lately with the Entrada although Butler in 1920 had already considered the sandstone at Bluff to be Salt Wash and therefore a part of the Morrison formation (then called McElmo). The more recent data showing the southward thinning of the San Rafael group and the presence of this group

in the beds under the contorted unit, together with a wider acquaintance with the variations in the lithology of the Morrison formation, have convinced the writers that the contorted beds at Bluff and over a large adjacent area are the basal part of the Morrison formation and that the overlying sandstone is therefore also Morrison."

As defined by Gregory the Bluff has only a limited distribution in the San Juan country, but he includes the "contorted beds" mentioned above in the San Rafael group.

As here interpreted the Bluff is a local phase of the widespread Entrada formation. This correlation is based on regional considerations, tracing of the units, and lithologic peculiarities. The Bluff "includes aggregates of large sand grains" (Gregory, 1938, p. 58), and in view of the widespread occurrence of this feature in the Entrada this must have considerable weight, since no beds known elsewhere in the Morrison show this habit.

The "Bluff" can be traced southward into the Carrizo Mountains, thinning from about 250 feet to about 15 feet. In the Carrizo Mountains it contains the usual large sand grains and overlies the crinkled beds of the old McElmo and is separated by about 175 feet of sediment from the Todilto limestone at Horse Mesa, 7 miles north of Red Rock, Arizona.

Adequate descriptions of the Entrada are given by Baker, Dane, and Reeside (1936), Baker (1933, p. 49), Dane (1935, p. 92), Gilluly and Reeside (1928, p. 78), and Gregory and Moore (1931, p. 76–80). The Bluff is described in detail by Gregory (1938, p. 58).

PONY EXPRESS LIMESTONE, BILK CREEK SANDSTONE, AND WANAKAH MARL

The lithology and correlation of the Pony Express limestone, Bilk Creek sandstone, and Wanakah marl have been treated in detail by Goldman and Spencer (1941). As these units were tentatively included as members in the Morrison formation a summary of the more important features is here given.

The Pony Express is a dense gray to black, unfossiliferous limestone. In places it is bituminous and locally it is replaced by gypsum or shale. The bedding is generally nodular and irregular. At some localities it is strongly brecciated; biscuit-shaped fragments and elongate masses were apparently kneaded into the overlying beds while still unconsolidated. The unit ranges from 2 to 15 feet in thickness.

This limestone was the original middle La Plata of Cross. The term Pony Express was first used by Irving (1905, p. 56) to designate the basal bed of the McElmo in a section of the Gold Hill, Ouray district, Colorado. Details of correlation are given by Goldman and Spencer, and the approximate geographic extent is shown on Figure 2.

The name Bilk Creek was proposed by Goldman and Spencer (1941, p. 1752) for a unit tentatively classified as a member of the Morrison formation. The unit is generally about 20 feet thick and has little topographic prominence as the cement is weak. The bedding is horizontal and in places nodular, the color is dull yellow to tan.

The Bilk Creek has a limited distribution in the San Juan Mountains and adjacent areas. It has been called the upper La Plata in parts of the Telluride and Ouray

folio areas. Goldman and Spencer have recognized the unit as far west as Uravan, Colorado. It apparently loses its identity and becomes part of the lower Summerville and of the marly equivalents of the Summerville in the Grand Junction area.

The name Wanakah marl was proposed by Burbank (1930) for the basal member of the Morrison in the Ouray district, Colorado. The name is derived from the Wanakah mine. As used by Burbank the term included the Bilk Creek and Pony Express, and the unit was treated as the lower member of the Morrison formation.

The Wanakah is 50 to 100 feet thick and consists of "hard, calcareous, concretionary, sandy, red, argillaceous beds" (Goldman and Spencer, 1941, p. 1749). The outcrop is generally dull-colored and talus-covered and forms a slope between sandstones above and below. No fossils have been found. The unit has a wide distribution in southwestern Colorado, and Goldman and Spencer have traced it to Uravan, Colorado. It is a time equivalent of the Summerville of the San Rafael area, and the two pass into each other by gradations in color and lithology along the general area of the central Utah-Colorado boundary. This agrees with the interpretations of Goldman and Spencer, but they had no opportunity for tracing the unit west of Uravan.

In exposures along the Gunnison River and over much of northwestern Colorado no equivalents of the Summerville have usually been recognized. The Morrison has been assumed to rest either on Curtis or on Entrada or older rocks. (*See* Baker, Dane, and Reeside, Figure 3, p. 18, Figure 5, p. 27, and Figure 6, p. 28.) Although direct tracing is possible only along the Gunnison River the writer believes that a certain amount of marly sediment, containing fresh-water molluscs and algae, generally included in the Morrison, is the equivalent of the Summerville and of the Wanakah.

JUNCTION CREEK SANDSTONE

The writer has not examined the Junction Creek sandstone in detail but agrees in general with the descriptions and conclusions of Goldman and Spencer who describe the unit as:

> "massive, whitish sandstone, generally with cross-bedding of the eolian type, and with considerable rounding of the grains. In many of its exposures, as in the Dolores Valley at and around Stoner and below McPhee, it is divided conspicuously into two parts, a lower more horizontally banded part with diagonal bedding within the horizontal layers, and an upper part with diagonal bedding on a large scale, that is, a single direction of diagonal bedding extending across a horizontal layer as much as 60 feet thick and continuing parallel with itself over long stretches, suggesting big decapitated dunes. This sandstone attains thicknesses as great as 500 feet. This is the white, cliff-forming sandstone of the White Cliffs on the East Mancos River on the west side of the La Plata Mountains" (1941, pp. 1749–50).

The Junction Creek is the true upper La Plata of Cross. It is underlain by the Pony Express limestone or associated marly beds and overlain by typical bentonitic clays and lenticular sandstones. The type locality is opposite Animas City Mountain, between Junction Creek and the Animas River about a mile north of Durango Colorado. Approximate distribution is shown by Figure 2.

Goldman and Spencer (1941, p. 1765), while they tentatively include the Junction Creek in the Morrison as a member, favor its exclusion on the basis that it is equiva-

lent to beds below the basal Morrison of east-central Utah. While the present writer cannot give an adequate analysis of this problem he believes that the Junction Creek is equivalent to part or all of the Salt Wash and should be retained as a member of the Morrison.

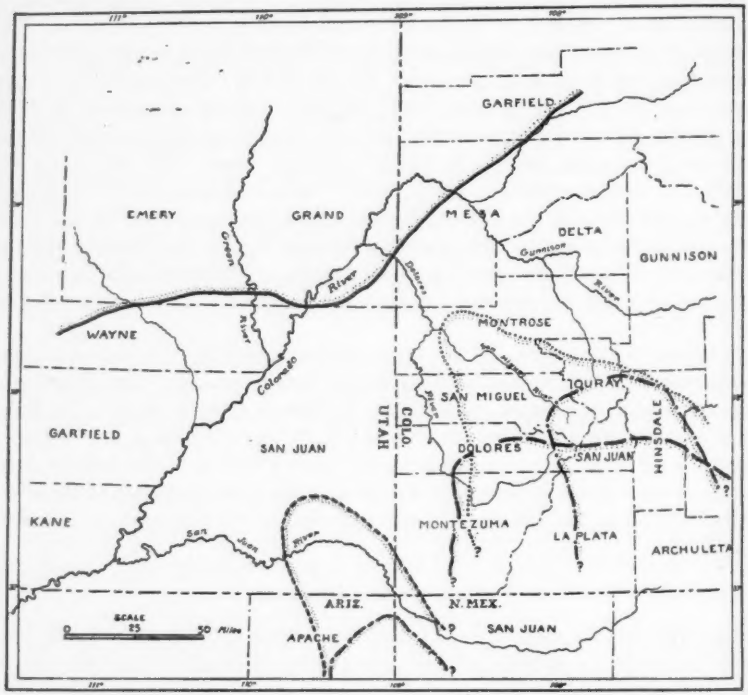


FIGURE 2.—*Map showing approximate limits of distribution of certain lithologic units in adjacent parts of Utah, Colorado, Arizona and New Mexico*

SALT WASH SANDSTONE, RECAPTURE SHALE, AND WESTWATER CANYON SANDSTONE

The Salt Wash sandstone was the first portion of the Morrison to be given member rank. It was proposed by Lupton (1914, p. 124) who used it as a datum plane for mapping in the Green River Desert. The type section is in Salt Wash, southeast of Greenriver, Utah. In 1916 Lupton traced this unit into the San Rafael area but confused it with what was to become the Curtis formation. Gilluly and Reeside (1928, p. 79) correctly identified the true Salt Wash as being 325 feet higher in the section. The unit is covered west of the San Rafael Swell, but near Hanksville and Cainville

and in the Henry Mountains it is thicker and more massive than at the type section or in the San Rafael area. Tracing of this unit toward the east and south is not difficult, and almost continuous exposures permit correlation with part of the Recapture shale member of the Morrison proposed by Gregory. Total extent of the unit in Arizona and New Mexico was not determined. Throughout southwestern Colorado and southeastern Utah the Salt Wash is topographically prominent and is easily recognized in McElmo Canyon where it constitutes most of the lower half of the abandoned McElmo formation. Along the lower part of the Gunnison River it is especially well developed but was not positively identified north and east of the Black Canyon of the Gunnison River. It thins and disappears toward the north and northeast and is apparently absent as a distinctive unit in the Uinta Mountains and in northwestern Colorado. The unit ranges in thickness from 100 to 300 feet.

The Salt Wash member consists of about equal amounts of shale and sandstone which alternate with and replace each other irregularly in every outcrop examined. This variability is highly distinctive, and the characteristic ledgy exposures can easily be recognized from place to place.

The sandstones are mainly gray with occasional yellow, white, or brown lenses. Individual beds range from 2 to 100 feet in thickness and are as much as 2 miles in length. The sandstones are apparently irregular segments of channel fills, and as far as can be determined they trend in a northeasterly or northerly direction. The constituent particles of the sandstone are mainly medium-sized quartz and chert fragments, and there are numerous soft kaolinized particles of undetermined origin.

The shales are generally red in the south and east parts of the area, but in the region of the San Rafael Swell and Green River Desert shades of gray and green are present. Shales immediately underlying sandstones and small shale lenses within sandstones are also green or gray, a color change apparently produced by groundwater action. The shales are somewhat bentonitic and are similar to those of the upper part of the Morrison.

The sandstones weather into rounded ledges, and the shales form small benches. Cement of the sandstone is weak, and the talus blocks are soon destroyed by weathering. Joints are rarely well developed. Bedding is variable, including tangential and angular types. A few small limestone lenses are present in the San Rafael area.

Dinosaur bones, especially the large limb bones of sauropods, are common. Silicified wood is present as well as occasional fragments replaced by gypsum or uranium and vanadium minerals. No fossils have been specifically identified and the absolute age of the unit is unknown.

The important deposits of uranium, vanadium, and radium in this member are discussed later.

As conglomerate is present in the vicinity of the Henry Mountains and as the Salt Wash is more massive toward the south and southeast, the source area was probably somewhere in those directions.

The Recapture shale was designated as a member of the Morrison formation by Gregory (1938, p. 58). The type section is near the mouth of Recapture Creek, San Juan County, Utah. As interpreted by the writer it includes the Salt Wash as well as about 150 feet of overlying alternating sandstones and shales. The Salt Wash is thin and rests directly on the Entrada (Bluff), and the Summerville is absent. In the

Carrizo Mountains the distinction between the Salt Wash and the overlying part of the Recapture is more clear cut, and the term Recapture can best be used for the upper part only, which is therefore a more restricted usage than Gregory employed. Gregory's description of the Recapture includes certain features of the Salt Wash, and the two are very similar in gross lithologic characteristics but differ in type of sandstone and shale and in appearance and manner of weathering.

The shales of the Recapture are mainly chocolate-brown, but pink, gray, and green are present in minor amounts. The sandstones are mainly gray and white with local lenses of pink, green, gray, and brown. The shales are somewhat sandy and flaky. The sandstones are generally tough and gypsiferous and weather without the production of talus blocks. Badlands with "hoodoos" are frequently produced. The outcrop is more irregular than that of the Salt Wash, but the lithic constituents are less resistant and hence do not form benches and flats of any great extent. The unit averages about 200 feet in thickness.

The Westwater Canyon sandstone was proposed as a member of the Morrison formation by Gregory (1938, p. 59). The type section is in Westwater Canyon, south of Blanding, Utah. Gregory suggested the equivalence of the Salt Wash and the Westwater Canyon, but this correlation seems unlikely in view of regional relationships. The Westwater overlies the Recapture and is similar to it in the alternation of shale and sandstone, but the color, bedding, and manner of weathering are different.

The shales are gray green with slight bluish tints, bentonitic and extremely friable. The sandstones are buff to yellow and tend to stand in vertical cliffs. The proportion of shale is somewhat greater than in underlying units, and the sandstones are more massive and persistent than those of the Salt Wash and Recapture. The unit averages 100–200 feet in thickness.

BRUSHY BASIN SHALE

The Brushy Basin shale is undoubtedly the most widespread member of the Morrison formation. Lithologically it has been referred to as "variegated shale," "joint clay," and "marl." These terms indicate its unusual characteristics and are commonly used in reference to the Morrison as a whole. The Brushy Basin member was proposed by Gregory (1938, p. 59) who designated Brushy Basin, west of Blanding, Utah, as the type locality.

Where vegetation is absent the typical erosion forms are low rounded hills with slopes that are convex outward. The sandstone and limestone which are interbedded with the shale are generally hard and firmly cemented. They supply talus blocks of all sizes and protect masses of shale from erosion and form irregular mesas and hogbacks. The Brushy Basin is generally protected from erosion by more resistant overlying beds, and the resulting cliff and varicolored slope are characteristic of the Morrison.

The Brushy Basin shale consists largely of the products of volcanic activity, mainly altered ash or bentonite, reworked and mixed with sand and silt in varying proportions. A sample of shale taken from the unit at Cedar Mountain, Emery County, Utah, contained fragments of hematite, zircon, plagioclase, biotite, and quartz.

The limestones are generally thin and lenticular. They are blue or gray on fresh fracture but weather to a deep yellow. They are siliceous, and small irregular fragments of replaced plant material are common. The sandstones and shales are remarkably varicolored; red, pink, green, purple, white, and brown are present in almost every good exposure. Generally the color bands are less than 3 feet thick, but some may reach 30 to 40 feet.

This member is the most fossiliferous of the Morrison and has yielded most of the dinosaur skeletons and petrified wood, the excellent preservation of which is no doubt due to the siliceous nature of the surrounding bentonitic shale. Bones from quarries as much as 500 miles apart are identical in color, manner of weathering, and composition. Table 2 shows the remarkable similarity of faunas collected in the larger

TABLE 2.—*Dinosaur genera from Morrison quarries*

Genera	1	2	3	4	5	6	7
Coelurus	X	X		X	X	X	
Antrodemus	X	X	X	X	X	X	
Ceratosaurus		X		X			
Laosaurus	X		X	X			
Dryosaurus	X		X		X		
Stegosaurus	X	X	X	X	X	X	X
Camptosaurus		X	X	X	X	X	
Camarosaurus	X	X	X	X	X	X	X
Apatosaurus			X	X		X	X
Diplodocus		X	X			X	X

1. Quarry 9, Como Bluff, Wyo. (Simpson, 1926, p. 3).
2. Malcolm Lloyd Quarry, Cleveland, Utah, Personal observations.
3. Dinosaur National Monument, Jensen, Utah (Gilmore, 1932, p. 7).
4. Canon City, Colo. (Marsh Quarry) (Gilmore, 1941, p. 25).
5. Quarry 13, Como Bluff, Wyo. (Gilmore, 1914, p. 4.)
6. Bone Cabin Quarry, Carbon Co., Wyo. (Osborn, 1904, p. 680–694).
7. Morrison, Colorado (Marsh, 1896, p. 526).

quarries which are, as near as can be determined, all in the Brushy Basin shale or its equivalents. Some of the questionable genera of sauropods are omitted. Many isolated finds also testify to the wide range of this Morrison dinosaur fauna, but very possibly many specimens, generally regarded as Morrison, have been collected in beds higher than true Morrison and may be Lower Cretaceous in age. Present knowledge of dinosaur structure and evolution is not sufficient to distinguish the Jurassic and Lower Cretaceous forms; in fact, such discrimination may have to be made on the basis of purely stratigraphic studies to determine the correct succession of forms.

The lower contact of the Brushy Basin is gradational. The upper contact is generally uneven, but no angular discordance has been noted. The overlying conglomerates rest on an eroded surface which exhibits in places marked color changes which may be due to weathering or leaching by ground water.

BUCKHORN CONGLOMERATE AND EQUIVALENTS

Units thus far discussed have been designated as members of the Morrison in previous reports. Formation names introduced in this paper include the Buckhorn

conglomerate and the Cedar Mountain shale. The Buckhorn conglomerate is especially prominent in the northern part of the San Rafael area where it caps Cedar Mountain, a tabular mass of Jurassic sediments about 75 square miles in extent. Buckhorn flat at the southwest flank of Cedar Mountain is designated as the type locality (Pl. 4, fig. 1). Here the unit is 20 to 30 feet thick, irregularly bedded with minor sandy lentils, but generally present as a single massive stratum. It is well cemented and durable at the type locality and generally has considerable resistance to erosion. The pebbles at the type locality average about 1¼ inches in diameter. Most of the pebbles are black chert, there are few sandstone, shale, or limestone fragments, and igneous rocks are rare.

The conglomerate forms dip slopes, hogbacks, and mesa tops. At the outcrop it erodes by loosening of individual pebbles or joint blocks which are strewn on adjacent slopes and flats far below the parent ledges. It is a persistent bench former.

Conglomerates which differ from the type Buckhorn in details of composition, weathering, and distribution are present at approximately the same stratigraphic horizon over wide areas in the Rocky Mountains. They are essentially synchronous deposits, and their differences are probably due to variation in source areas and to conditions of deposition. A facies present over wide areas in southern Utah is composed of more brilliantly colored cherts and other siliceous material. Red, yellow, brown, and white are common, and there are occasional small green pebbles which are valuable index markers for this bed. The average size of the pebbles is about half an inch, and at the northern edge of its range the whole conglomerate is little more than a coarse sand. This facies contains many well-rounded quartz grains, evidently shaped by wind action, but very little finer material. It seems to be a lag gravel produced by deflation and winnowing action of wind. At the Henry Mountains the cement is red amorphous siliceous material; at other places it is gray or white. This conglomerate is probably lower in the section than true Buckhorn.

The lower part of the Kelvin conglomerate and Mansfield's "black chert conglomerate" in the Ephraim formation are tentatively correlated with the Buckhorn as well as the lower conglomerate of the Cloverly in adjacent areas of Wyoming and northern Colorado.

CEDAR MOUNTAIN SHALE

The term Cedar Mountain shale is proposed to include the variegated beds between the Buckhorn conglomerate and the Dakota (?). The type section and locality is at the southwest flank of Cedar Mountain, Emery County, Utah, just north of the Buckhorn Reservoir. This unit has many features in common with the Brushy Basin shale, but the differences warrant its recognition as a distinct formation.

The lower boundary has been discussed in connection with the Buckhorn. It depends on the local position of the conglomerates and may vary within a vertical interval of 100 feet or more. The shale-conglomerate contact is sharp; the plane of junction generally is a dip slope where exposed. The upper contact is variable; in places it is gradational into Dakota (?) beds, elsewhere it is sharp but irregular.

The color of the Cedar Mountain beds is variable, but it is almost always more dull and subdued than that of the Brushy Basin (Pl. 4, fig. 3). Narrow color bands

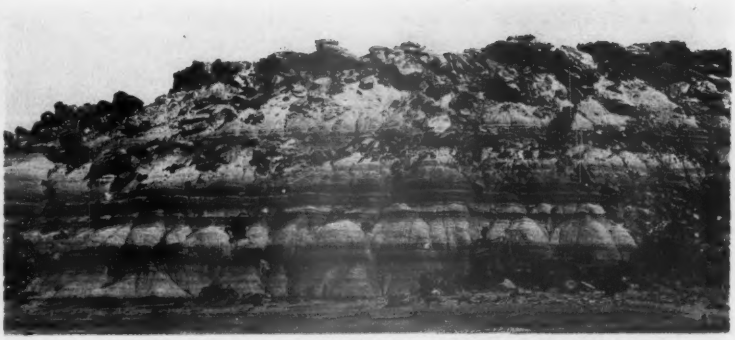


FIGURE 1. BRUSHY BASIN SHALE MEMBER OF MORRISON FORMATION
Thirteen miles southwest of Green River, Utah. Ledge at skyline is Buckhorn conglomerate. Figure of man at base of slope gives scale. (Photograph by A. A. Baker, Courtesy U. S. Geol. Survey)

FIGURE 2. WESTWATER CANYON AND RECAPTURE SHALE MEMBERS OF MORRISON FORMATION
View about 8 miles northwest of Tes Nos Pas Trading Post, Arizona. W, Westwater Canyon member; R, Recapture shale member. Upper part of butte is Brushy Basin shale.

FIGURE 3. SALT WASH SANDSTONE MEMBER OF MORRISON FORMATION
View taken ¼ mile west of Slick Rock P. O., Colorado. Upper sandstone contains important vanadium deposits in this area.

TYPICAL EXPOSURES OF MEMBERS OF MORRISON FORMATION

FIGURE 1. BUCKHORN CONGLOMERATE AT TYPE SECTION
View taken below dam of Buckhorn reservoir. Total thickness exposed about 25 feet.

FIGURE 2. TYPE LOCALITY OF CEDAR MOUNTAIN FORMATION
View taken 6 miles southeast of Cleveland, Utah. Tree-covered terrain in right distance is a dip slope on Buckhorn conglomerate. "Dakota (?)" caps hill at left.

FIGURE 3. BRUSHY BASIN MEMBER OF MORRISON FORMATION OVERLAIN BY CEDAR MOUNTAIN SHALE
Contact at top of ledgy sandstones. Note difference in color banding, lithology, and manner of weathering. Cow Flat, north of Cedar Mountain, Emery County, Utah.

CEDAR MOUNTAIN GROUP

are lacking, and one shade generally persists through a score or more feet, grading imperceptibly into other colors. At Cedar Mountain the lower part is light red to purple, and the upper dull gray to white.

Badlands with sharply exposed joint and stratification planes are seldom formed, and slopes are gentle. Most exposures are covered with weathered-out concretions and nodules, and these are especially plentiful and characteristic in the region of the San Rafael Swell and eastward to the Colorado-Utah boundary. Botryoidal forms of red and blue chalcedony as well as septarian nodules filled with varicolored and banded siliceous material are common. Some concretions contain barite, and others calcite or strontianite crystals.

A striking feature is the presence of numerous elongate sandstone lenses, evidently channel fills. Where the beds are horizontal these weather out in detail and can be traced as low winding ridges up to a mile in length. The direction of greatest elongation is generally from southwest to northeast, which suggests the source of sediments and the slope of the terrain.

A few scattered dinosaur bones constitute all the organic remains so far observed. These are broken, disarticulated, and apparently water-worn. The replacing material is yellow or red, seldom black like that of the Brushy Basin remains.

Over most of the area adjacent to the San Rafael Swell and eastward to and beyond the Colorado-Utah line these beds contain most of the "gastroliths" of the Morrison. There seems to be a definite relationship between the distribution of these stones and Buckhorn conglomerate. The "gastrolith" rock types can be identified as having a source in the Buckhorn, and the few fossils, including fusulines which have been found in "gastroliths" are Carboniferous and Permian types such as occur in pebbles of the conglomerate. In the exposures around the Uinta Mountains and northward "gastroliths" are plentiful, but their distribution is not so strictly confined to a certain portion of the Morrison, although they are much more common in the upper part.

The Cedar Mountain formation thins to the east as indicated by the following figures: type section at Cedar Mountain, 272 feet; Greenriver, Utah, 111 feet; Cisco, Utah, 100 feet; Blue Mountain, Colorado, 25 feet; Little Snake River, Colorado, 10 feet. At the Little Snake River some of the pebbles in the "Dakota" are fragments of a prelithified chert conglomerate that have every appearance of being the Buckhorn. The Cedar Mountain formation thus has its greatest development in central Utah and northwestern Colorado. It is not easily recognized where the heavy-bedded, yellow sandstone facies of the Dakota (?) is present, and the two appear to be partially equivalent.

POST-McELMO BEDS

In 1921 Coffin proposed the term "Post-McElmo" for certain beds between the McElmo and Dakota of southwestern Colorado. He felt that they were insufficiently known for the application of a new formational name but stressed the fact that they could not be included with either the underlying or overlying beds without exceeding the limitations of type sections.

Coffin defined these beds as follows:

> "The two units, "Post-McElmo" and "Dakota" include strata between two easily recognized limits . . . the bottom of a massive sandstone conglomerate as a base, and the dark Mancos shales as an upper limit.
>
> "In regions where the "Dakota" is separated from the Post-McElmo the division is made at the base of the first sandstone or conglomerate which underlies the lowest carboniferous shale or coal horizon" (Coffin, 1921, p. 98).

The basal part of the Post-McElmo which generally outcrops as a cliff has an irregular contact with the McElmo (here used in the sense employed by Coffin). Chert and cherty limestones are common, and the shales are similar to those in the McElmo below. No fossils are known, and the age is doubtful. Coffin placed the unit in the Cretaceous with the following comment:

> "Certainly the massive sandstone conglomerate and the unconformity used as the upper limit of the McElmo mark a definite change of conditions of sedimentation. Above this massive stratum are beds of more or less pure limestone, massive beds of chert and much green shale, strata the like of which have never been included in the Dakota" (Coffin, 1921, p. 98).

Since Coffin's work the term McElmo has been abandoned, and as the term Morrison has been applied liberally it now includes the Post-McElmo as well as the McElmo. The correlation of the Post-McElmo and the Cedar Mountain shale is suggested as probable, but exact determinations must await further study.

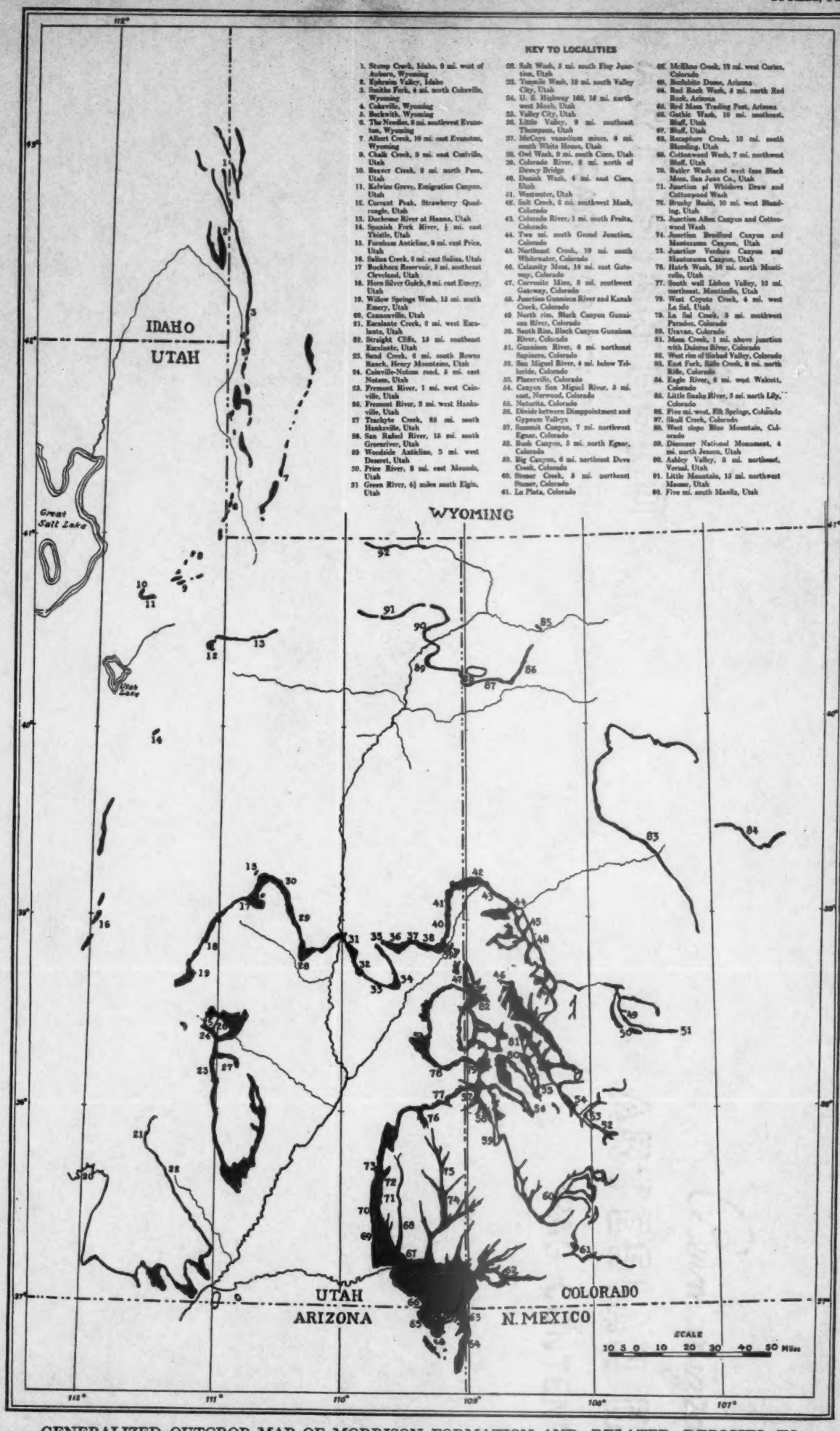
DAKOTA FORMATION

The Dakota formation presents problems of age, correlation, and lithology similar to those of the Morrison. The two have an almost identical distribution, and their contact has long been assumed to mark the Jurassic–Upper Cretaceous time interval over wide areas in the Rocky Mountains. Evidence suggests that thin sedimentary units of Lower Cretaceous age may lie above the Morrison and that the Dakota is in places Lower Cretaceous in age. In view of the uncertain status of some of these beds the United States Geological Survey has adopted the term Dakota (?) to include them, and this designation is useful until the different parts of the assemblage are sufficiently well known for the application of names.

GANNETT GROUP

The Gannett group lies above the Upper Jurassic Stump sandstone of southeastern Idaho. It includes five formations: the Ephraim conglomerate, Peterson limestone, Bechler conglomerate, Draney limestone, and Tygee sandstone. On the basis of fossils from the Peterson and Draney the whole group is designated as questionably Lower Cretaceous, but the evidence is meager. Although detailed studies are lacking this group probably represents the middle portion of the Beckwith formation of adjacent areas in Wyoming. The whole group, some 3200 feet thick, is truncated by an erosion surface which bevels the formations eastward and is the base of the Wayan group of Cretaceous age.

Evidence for the equivalence of the Stump sandstone, the Curtis formation, and the Upper Sundance (Neely, 1937) is considered well established. There is little


KEY TO LOCALITIES
1. Stump Creek, Idaho, 9 mi. west of Auburn, Wyoming
2. Ephraim Valley, Idaho
3. Smiths Fork, 4 mi. north Cokeville, Wyoming
4. Cokeville, Wyoming
5. Bockwith, Wyoming
6. The Needles, 8 mi. southwest Evanston, Wyoming
7. Albert Creek, 10 mi. east Evanston, Wyoming
8. Chalk Creek, 5 mi. east Coalville, Utah
9. Beaver Creek, 9 mi. north Peoa, Utah
10. Kelvins Grove, Emigration Canyon, Utah
11. Currant Peak, Strawberry Quadrangle, Utah
12. Duchesne River at Hanna, Utah
13. Spanish Fork River, 3 mi. east Thistle, Utah
14. Farnham Anticline, 9 mi. east Price, Utah
15. Salina Creek, 6 mi. east Salina, Utah
16. Buckhorn Reservoir, 5 mi. southeast Cleveland, Utah
17. Horn Silver Gulch, 8 mi. east Emery, Utah
18. Willow Springs Wash, 13 mi. south Emery, Utah
19. Cannonville, Utah
20. Escalante Creek, 2 mi. west Escalante, Utah
21. Escalante, Utah
22. Straight Cliff, 13 mi. southeast Escalante, Utah
23. Sand Creek, 6 mi. south Bowns Ranch, Henry Mountains, Utah
24. Caineville-Notom road, 3 mi. east Notom, Utah
25. Fremont River, 1 mi. west Caineville, Utah
26. Fremont River, 3 mi. west Hanksville, Utah
27. Trachyte Creek, 25 mi. south Hanksville, Utah
28. San Rafael River, 15 mi. south Greenriver, Utah
29. Woodside Anticline, 3 mi. west Deseret, Utah
30. Price River, 3 mi. east Mounds, Utah
31. Green River, 4½ miles south Elgin, Utah
32. Salt Wash, 5 mi. south Flop Junction, Utah
33. Temple Wash, 10 mi. south Valley City, Utah
34. U. S. Highway 160, 16 mi. northwest Moab, Utah
35. Valley City, Utah
36. Little Valley, 9 mi. southeast Thompson, Utah
37. McCoys vanadium mines, 6 mi. south White House, Utah
38. Owl Wash, 9 mi. south Cisco, Utah
39. Colorado River, 2 mi. north of Dewey Bridge
40. Dunish Wash, 4 mi. east Cisco, Utah
41. Westwater, Utah
42. Salt Creek, 2 mi. southwest Mack, Colorado
43. Colorado River, 1 mi. south Fruita, Colorado
44. Two mi. south Grand Junction, Colorado
45. Northeast Creek, 10 mi. south Whitewater, Colorado
46. Calamity Mesa, 14 mi. east Gateway, Colorado
47. Carvonite Mine, 2 mi. southwest Gateway, Colorado
48. Junction Gunnison River and Kanab Creek, Colorado
49. North rim, Black Canyon Gunnison River, Colorado
50. South Rim, Black Canyon Gunnison River, Colorado
51. Gunnison River, 6 mi. northeast Sapinero, Colorado
52. San Miguel River, 4 mi. below Telluride, Colorado
53. Placerville, Colorado
54. Canyon San Miguel River, 5 mi. east, Norwood, Colorado
55. Naturita, Colorado
56. Divide between Disappointment and Gypsum Valleys
57. Summit Canyon, 7 mi. northwest Egnar, Colorado
58. Bush Canyon, 3 mi. north Egnar, Colorado
59. Big Canyon, 6 mi. northeast Dove Creek, Colorado
60. Stoner Creek, 5 mi. northeast Stoner, Colorado
61. La Plata, Colorado
62. McElmo Creek, 12 mi. west Cortez, Colorado
63. Redbabito Dome, Arizona
64. Red Rock Wash, 5 mi. north Red Rock, Arizona
65. Red Mesa Trading Post, Arizona
66. Gothic Wash, 10 mi. southeast, Bluff, Utah
67. Bluff, Utah
68. Recapture Creek, 12 mi. south Blanding, Utah
69. Cottonwood Wash, 7 mi. northwest Bluff, Utah
70. Butler Wash and west fork Black Mesa, San Juan Co., Utah
71. Junction of Whiskers Draw and Cottonwood Wash
72. Brushy Basin, 10 mi. west Blanding, Utah
73. Junction Allen Canyon and Cottonwood Wash
74. Junction Bradford Canyon and Montezuma Canyon, Utah
75. Junction Verdure Canyon and Montezuma Canyon, Utah
76. Hatch Wash, 10 mi. north Monticello, Utah
77. South wall Lisbon Valley, 12 mi. northeast, Monticello, Utah
78. West Coyote Creek, 4 mi. west La Sal, Utah
79. La Sal Creek, 3 mi. southwest Paradox, Colorado
80. Uravan, Colorado
81. Mesa Creek, 1 mi. above junction with Dolores River, Colorado
82. West rim of Sinbad Valley, Colorado
83. East Fork, Rifle Creek, 8 mi. north Rifle, Colorado
84. Eagle River, 6 mi. west Walcott, Colorado
85. Little Snake River, 3 mi. north Lily, Colorado
86. Five mi. west Elk Springs, Colorado
87. Skull Creek, Colorado
88. West slope Blue Mountain, Colorado
89. Dinosaur National Monument, 4 mi. north Jensen, Utah
90. Ashley Valley, 5 mi. northeast, Vernal, Utah
91. Little Mountain, 15 mi. northwest Mesner, Utah
92. Five mi. south Manila, Utah
IDAHO
UTAH
WYOMING
Great Salt Lake
Utah Lake
UTAH
COLORADO
ARIZONA
N. MEXICO
SCALE
10 5 0 10 20 30 40 50 Miles
112°
111°
110°
109°
108°
107°

GENERALIZED OUTCROP MAP OF MORRISON FORMATION AND RELATED DEPOSITS IN PORTIONS OF UTAH, COLORADO, NEW MEXICO, ARIZONA, WYOMING AND IDAHO

Numbers indicate localities examined by the writer

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evidence for a long period of nondeposition between the withdrawal of the Jurassic sea and the beginning of terrestrial sedimentation, in any area, and this has led the writer to seek for Morrison equivalents in the Gannett group. The type section of the Ephraim conglomerate was visited, as well as other exposures along the Idaho-Wyoming line. On Stump Creek, Idaho, 2 miles west of Auburn, Wyoming, a typical Morrison sequence is present in the Ephraim. Above the Stump lies about 200 feet of drab shale, then 20 to 30 feet of black chert conglomerate, then red shales, sandstones, and nodular limestones, several hundred feet thick. In the last unit a good collection of typical "gastroliths" was obtained, including characteristic lithologic types also present 500 miles distant in central Utah. The posterior half of a caudal vertebra, resembling that of an *Allosaur* or *Allosaur*-like dinosaur, was also found. The evidence though meager indicates that all or part of the Morrison and Cedar Mountain is probably equivalent to the Ephraim conglomerate and contiguous formations of the Gannett group.

BECKWITH FORMATION

The Beckwith formation of southeastern Idaho has been studied and subdivided by Mansfield and Roundy (1917), but the type section near Beckwith, Wyoming, has not been restudied since its original designation by Veatch (1907). The name Beckwith applies to large areas in southwestern Wyoming and also portions of Utah (Boutwell, 1933, p. 58–64) where its equivalence to the Morrison has been assumed.

The author visited the type section of the Beckwith near Beckwith Station, Lincoln County, Wyoming, and also exposures east of Cokeville and on Smith's Fork. At these places the Beckwith rests on the Twin Creek. The lower part of the Beckwith is obviously the same as the Preuss of southeastern Idaho. The Stump is also recognizable. This marine horizon was noted by Veatch (1907, p. 57), but the implications of the fossil evidence were not fully realized at that time. Above the Stump equivalent lies a series of red shales, and succeeding this are conglomerates interbedded with shale.

Near the base of the conglomerate series and in a typical Morrison-like bentonitic shale numerous well-polished "gastroliths" were found, which is evidence for the equivalence of some part of the Morrison or Cedar Mountain beds with this part of the Beckwith. The conglomerates consist mainly of chert with a few limestone pebbles, all stained red or pink on the surface. A few thin layers of blue nodular limestones are interbedded with the conglomerates.

The upper limit of the Beckwith near Cokeville was not determined, but it should probably be placed where the red conglomerates give way to gray, less coarsely clastic beds. The whole series needs revision, but the evidence favors the conclusion that the Morrison and a portion of the Beckwith are equivalent.

Plate 5 shows a diminishing number of outcrops extending southward from the type section of the Beckwith. The original continuity between these and the well-established Morrison outcrops near Wanship and Peoa, Utah, seems to be indicated by structural, lithologic, and stratigraphic considerations, but conclusive evidence is lacking.

CURRANT PEAK SECTION

The Currant Peak section (T. 1 S., R. 11 W., Salt Lake Base and Meridian, Strawberry quadrangle, Utah) contains all the units found elsewhere in this general region. It may be taken as a standard with which to compare the incomplete and structurally complex sequences of such adjacent localities as Parleys Canyon, Coalville, and Peoa. It also serves as a tie-in with exposures along the south flank of the Uinta Mountains. At Currant Peak the marine Jurassic is overlain by approximately 600 feet of red shale. Above this, interbedded shales and conglomerates occupy an interval of about 1200 feet, succeeded by 950 feet of shale and sandstones, red at the base but merging gradually into gray toward the summit. The Aspen shale, easily recognized by the abundant teleost fish scales, is at the top of the section.

The conglomerates show an interesting gradation in the rock types of the constituent pebbles. The pebbles of the lowest conglomerates are approximately 90 per cent chert and thus resemble the Buckhorn and its equivalents. As the section is ascended each successive conglomerate shows a decrease of chert and an increase of quartzite until in the highest the pebbles are about 90 per cent quartzite, thus approaching the typical western facies of the "Dakota". "Gastroliths" are present in the intervening shales. The gray and light-red beds above the conglomerate are identical with the "terra-cotta" beds near Coalville and occupy a similar position in the sequence. The conglomerates are probably equivalent to the Kelvin, the upper shales to the "terra-cotta beds," and the lower shales to typical Morrison of regions to the east and south.

KELVIN CONGLOMERATE

The Kelvin conglomerate was named by Mathews (1931, p. 48), from exposures of Kelvins Grove in Emigration Canyon about 8 miles east of Salt Lake City. Here, it is a conspicuous formation of interbedded shale, sandstone, and coarse conglomerate. Structural complications make measurements untrustworthy, but the whole is several hundred feet thick. The Kelvin varies rapidly from place to place both in thickness and gross lithology. The chief constituent of the conglomerate is light-colored quartzite pebbles from 1 to 8 inches in diameter. The source of this conglomerate is obviously near, as fragments of this size could not have been transported far. A detailed examination of many of the sandstone and quartzite pebbles failed to reveal fossils, but the physical characteristics are very similar to those of the quartzites of the Carboniferous Oquirrh series, and these are a very probable source for the Kelvin. The lack of banded and colored pebbles seems to rule out the pre-Cambrian quartzites of the area as a source. Colored pebbles are very common in Tertiary and Quaternary deposits known to have been derived from the pre-Cambrian rocks of the Uinta Mountains. Other rock types present in the Kelvin are shale, limestone, and chert. The chert is a very minor constituent near the type section, but it becomes more common eastward.

The Kelvin is considered equivalent to the Cedar Mountain group. Its lowermost conglomerates correspond to the Buckhorn, and the uppermost to the "Dakota". Owing to its rapid variation and irregular deposition it cannot be traced, with confidence, for any great distance from the type section.

PALEOGEOGRAPHY AND LITHOGENESIS

STRUCTURAL AND STRATIGRAPHIC SETTING

Two extensive marine invasions and the interval of uplift and erosion between them are responsible for most of the upper Jurassic and Cretaceous stratigraphic record of the Rocky Mountain region. If minor irregularities are disregarded the

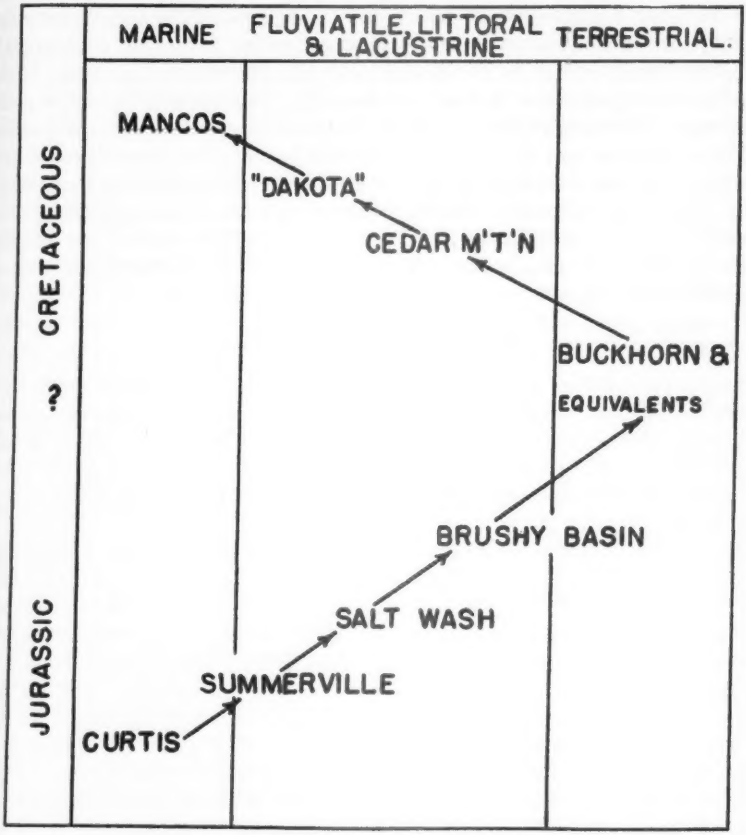

FIGURE 3.—*Generalized sedimentary cycle for the Colorado Plateau*

sequence of sedimentation from marine to terrestrial and back to marine constitutes a fairly regular cycle. Figure 3 shows some of the representative units in terms of their position in the cycle and the environments created by the relative positions of land and sea. It is highly generalized and is intended to show average conditions over the area involved.

The orderly deposition of widespread upper Jurassic and Cretaceous beds over the Colorado Plateau has been largely due to the stability of that unit in its reaction to

diastrophism. The Colorado Plateau has acted as a buttress against which successive waves of diastrophism, coming mainly from the west, have broken and spent themselves. The Mesocordilleran geanticline which roughly separates the Great Basin and the Colorado Plateau has been a zone of recurrent activity since the Middle Paleozoic.

In the Triassic, Jurasic, and late Cretaceous the region of the Colorado Plateau was the locus of large-scale sedimentation. During most of the Late Triassic and Early Jurassic the deposition of aeolian sandstone typified by the Glen Canyon group progressed uninterrupted by marine invasion. The source of the sand may be the pre-Cambrian quartzites of Arizona, and the aridity suggests lofty mountains to the southwest. This great wedge of sandstones thins and disappears in central Wyoming.

The eroded remnants of the Colorado Rockies formed a low barrier between the deserts of the west and the interior of the continent. How prominent these mountains were in Jurassic time is difficult to determine because of complications introduced by later intense deformation. The Colorado Rockies were low and supplied little detritus to Jurassic basins. West of the Colorado Rockies practically no pebbles of pre-Cambrian rocks have been found in the Morrison.

JURASSIC MARINE TRANSGRESSIONS

In late Jurassic time a shallow marine invasion advanced into the depression between the Colorado Rockies and the Mesocordilleran geanticline. The embayment of marine waters extended roughly to the southern boundary of Utah and as far east as the Black Hills, avoiding in general the region of the Colorado Rockies. Over most of its southern extent the transgression was over a surface of Nugget and Navajo sandstone.

The marine organisms are of Boreal types like those of Alaska and Siberia, contrasting with the faunas of the Jurassic of California, Nevada, and Oregon which are of central European character. The exact configuration of land barriers and sea connections at this time is imperfectly known, but as indicated by the faunas there was no connection between the waters of the Carmel (Twin Creek) Sea and those west of the Mesocordilleran geanticline or with the Gulf of Mexico area. The junction with the open ocean was evidently so far away that concentration and precipitation of gypsum were possible, especially in the southern Utah area. The presence of abundant gypsum in the Todilto has an important bearing on correlation. If the Todilto is considered equivalent to the Carmel the origin of the gypsum is easily explained as a result of evaporation and concentration of marine waters. If the Todilto is considered the basal member of the Morrison it must have been deposited after the withdrawal of the sea and hence have an origin other than precipitation from sea water. Baker, Dane, and Reeside state:

> "Lee and others have advanced the idea that the thick gypsum deposits assigned in the present paper to the base of the Morrison could not have formed without an abundant supply of sea water. Certainly there are substantial beds of gypsum within the San Rafael group and in close association with fossiliferous marine deposits, though the writers think that the discontinuous beds of gypsum associated with the Morrison do not demand sea water as an essential to their formation." (1936, p. 63.)

The limestone facies of the Todilto is regarded as of fresh-water origin but it is entirely probable that shallow playa lakes and embayments may have been supplied by either salt or fresh water depending on local conditions. The land surface was probably so near sea level that a very slight change would alter the strand line over wide areas. This suggests that the sea actually advanced far beyond the known fossiliferous facies. If shallow waters alternated with emergent conditions no extensive colonies of marine animals could have developed. Playa lakes and shallow embayments of the ocean permitted stratification of fine-grained material, while, along the margins of the sea, deposition of sand by wind went on continuously. The extent of this desert area to the south and east is unknown, but the isthmus between the waters of the Carmel Sea and those of the Gulf area must have been hundreds of miles across.

The fact of two marine invasions during the upper Jurassic was established in the San Rafael area with the finding of marine fossils in both the Carmel and the Curtis (Gilluly and Reeside, 1928). Later, Neely (1937) found the Sundance of Wyoming to be bipartite, indicating a retreat of the sea and an interval of erosion followed by sandstone deposition. A similar sequence is found in southeastern Idaho where the fossiliferous Twin Creek and Stump formations are separated by the Preuss. The sea was absent from the entire area for practically all the Divesian if correlations with European standards are accurate.

The Entrada sandstone was deposited mainly during the interval of withdrawal but was probably subaqueous in places. The next overlying formation, the Curtis, is separated from the Entrada in the San Rafael area by an erosional unconformity and a basal conglomerate with fragments of chert, shale, sandstone, and limestone. The marginal areas of the Jurassic basin probably witnessed continued desert conditions and the deposition of the sandstone facies of the Entrada. In the more central areas temporary bodies of shallow water were sufficient to permit stratification of the sediments now included in the silty facies. Absence of fossils indicates environments unfavorable to vegetation or animal life.

The sandstone deposited marginal to the marine deposits, although very thin in most places, is remarkably widespread. Heaton (1939, p. 1155) has traced it over extensive areas in Utah, Colorado, and New Mexico and suggests that the Entrada is the same as the "Sundance sand" of Wyoming. This supports the correlations offered in this paper, which indicate that the Bluff is equivalent to the upper portion of the Entrada and to Lower La Plata of older terminology. The lack of coarse clastics in this bed and the absence of unconformities of any great magnitude indicate the extreme flatness of the upper Jurassic terrain. Some vestige of the old pre-Cambrian highlands still remained above the sand, for at the Black Canyon of the Gunnison River the Summerville equivalents lie on the crystalline rocks with only sporadic, thin patches of sandstone. Farther east there is no sandstone, and the Morrison rests directly on the granite. In the Mesocordilleran geanticline the land was probably high enough for the erosion of some clastic material such as appears in the basal Curtis of the San Rafael Swell.

The second marine invasion must also have been more widespread than is indicated by the fossiliferous facies. Only six identifiable species have been reported from the

type locality of the Curtis or near it. That the Curtis can be correlated with beds generally called Twin Creek in the Uinta Mountains is indicated by the presence of glauconite in both and by the nature of the confining beds.

The Curtis formation passes into Summerville type lithology in the Green River Desert (McKnight, 1940, p. 98). The Summerville is characterized by even bedding which suggests marine or at least subaqueous origin. In Lemon Flat on the northern flank of Cedar Mountain numerous impressions of small pelecypods were observed in the Summerville but whether these are marine cannot be determined. Abundant gypsum is interbedded with the shales, and there is generally a bed several feet thick at the top. On the basis of these facts the Summerville is considered to have originated in shallow water, probably marine, where certain cyclic alternations of deposition occurred.

The thin bedding which is more characteristic of the Summerville occurs locally in the Curtis and the Entrada and indicates a type of environment undoubtedly repeated many times in the shallow Jurassic seaway (Pl. 2, fig. 3).

Marginal to the Summerville are calcareous beds, some of which constiture the Wanakah marl. The ostracods (unstudied) and Algae of these marls suggest fresh-water origin which is compatible with the paleogeography as a whole. After the final retreat of the Logan Sea conditions of drainage become such that deposition of marl ceased as did also the thin-bedded sediments of the Summerville.

TERRESTRIAL SEDIMENTATION

After the complete withdrawal of the sea the Salt Wash sandstone member of the Morrison was deposited. The irregular bedding of this unit is difficult to interpret, but the constant reworking and destruction of old river channels by new ones and a consequent production of irregular short segments probably accounts for the observed facts. The shale lenses were probably deposited on flood plains and in quiet waters on an extensive plain only slightly above sea level. Carbonaceous seams, petrified logs, dinosaur bones, and impressions of reedlike plants are fairly common and indicate an environment evidently more favorable to terrestrial life than that which prevailed earlier in the Jurassic.

Deposits of vanadium, uranium, and radium minerals have a sporadic distribution in sandstones of the Salt Wash member. Carnotite and tyuyamunite are the important uranium minerals, and vanoxite, rossite, metarossite, hewettite, metahewettite, and corvusite are common vanadium minerals. These minerals generally impregnate sandstones and replace fossil trees and shale pellets.

In areal distribution the ore deposits range from the Blue Mountains, Colorado, to the Carrizo Mountains, Arizona, and from the Henry Mountains, Utah, to the longitude of Uravan and Egnar, Colorado. Deposits are also found in the Entrada sandstone at Rifle, Placerville, and near Durango, Colorado, but the composition and mode of occurrence of the ore in the Entrada is not the same as in the Salt Wash. The Morrison ore bodies are confined with few exceptions to sandstones in the Salt Wash and are generally restricted to certain zones within that member. Faults, folds, and igneous intrusions of various kinds cut and deform the vanadium-bearing

beds but have no apparent effect on the distribution of the ore. As the ore bodies cut across bedding planes, fossil trees, cross-bedding, and other original stratigraphic features a syngenetic origin seems improbable. It is generally agreed that the ores were deposited by circulating waters shortly after the deposition of enclosing sediments, but details governing the localization of the ore bodies are not understood. The ultimate source of the vanadium, radium, and uranium is another problem for which the following solutions have been proposed: (1) concentration from waters of ordinary composition by organic agencies, (2) leaching from overlying shale beds, which are largely bentonite, (3) precipitation from waters of more than usual vanadium and uranium concentration by factors not fully understood.

One possible source for the vanadium and uranium is the pre-Cambrian crystalline rocks exposed in the cores of the Colorado Rockies, which were not entirely buried until late Jurassic time. The presence of vanadium in the Entrada at Rifle, Placerville, and Durango, which are near the margins of the Colorado Rockies, supports this view. In a general way the concentration of ore diminishes away from west-central Colorado, and in such areas as the San Rafael Swell, Kaiparowits Plateau, and the Uinta Mountains only the more soluble and hence mobile minerals are found. As will be shown the immediate source for much of the Morrison was Triassic and upper Paleozoic rocks lying to the south, southwest, and west. Triassic formations of the Rocky Mountains contain concentrations of many minerals that include uranium and vanadium. The Permian Phosphoria formation also contains significant concentrations of vanadium in parts of Idaho and Wyoming; equivalents of this formation may have been destroyed to form late Jurassic rocks.

The Salt Wash grades upward into the Brushy Basin member of the Morrison which consists of much finer sediments. The shallow basin left by the withdrawal of the Logan Sea was not completely filled until much terrestrial sediment had accumulated. After this the surface became a nearly true plane, probably very near sea level, sloping generally toward the northeast. The conditions at this time are considered typically Morrison and are best described by Mook (1916, p. 164), whose excellent paper is a pioneer attempt at a paleogeographical interpretation of the problems of Morrison sedimentation:

> "To the present writer the best explanation of the origin of the Morrison formation appears to be that of a number of large streams issuing from a mountainous area and crossing a very broad, flat plain. Such streams would deposit much of their loads on their flood-plains in the form of very flat alluvial fans. Deposition by distributaries, aided by tributaries and aeolian action, would tend to unite these fans into a broad alluvial plain. The main streams and tributaries consequent on the plain would gradually extend such alluvial deposits over a very broad area. In local basins between the principal stream areas and in abandoned stream valleys lakes would probably form locally. In these lakes fine sediments would be deposited, with sandstones around the margins. Aeolian deposits would probably form to a certain extent between main stream areas."

The above picture does not take into account the part played by volcanic ash in building up the Morrison, as indicated by the bentonites. The evidence for the existence of great river systems and alluvial deposits is not strong since the areas to the west from which the sediments were derived show no great increase of clastic material. Temporary lakes were no doubt present, but, surrounding these, typical desert conditions may have prevailed to an extent not fully appreciated. The dino-

saur fauna does not necessarily indicate lush vegetation and tropical conditions, and the paucity of plant remains is hard to explain if a well-watered terrain is postulated.

The predominance of fine sediments and the absence of unconformities and stream channels indicate a long undisturbed period of sedimentation. The remarkable similarity of this deposit over 360,000 square miles can be duplicated by few other terrestrial deposits, but it resembles the deposits laid down in the more stable and uniform environments of the ocean bottom.

BUCKHORN CONGLOMERATE

A temporary halt in sedimentation is indicated by the unconformity at the base of the Buckhorn and its equivalents. Some hypothesis is needed to explain: (1) the cessation of active sedimentation, (2) the erosion of deposits already laid down, and (3) the formation of a thin gravel sheet over a very wide area. The writer believes this portion of the sequence can be best explained by regional uplift followed by a long period of still-stand and limited local sedimentation under conditions of arid or semi-arid climate.

Over areas where the Morrison now exists uplift may have been slight, just enough to swing the geologic processes from construction to destruction over a plain already nearly at base level. To the west acute mountain building and attendant volcanism may have occurred. The relation of widespread gravel sheets to diastrophism is more difficult to determine and requires a consideration of similar occurrences both ancient and recent. The association of conglomerates and bentonites is not peculiar to the Morrison. These lithologic types are indicators of recurrent geologic processes and are found associated several times in the area east of the Mesocordilleran geanticline.

While acute mountain building may be localized in relatively narrow zones the effects are widespread and can be recognized for great distances. The sudden appearance of coarse transported detritus over wide continental areas seems to indicate rejuvenation and consequent erosion. Similarly volcanic outbursts are limited in geographic extent, but their products are dispersed by winds and water over wide areas. A single layer of volcanic ash is an extremely valuable datum plane even though the point of origin is unknown.

The bentonite-conglomerate association is present in the Triassic beds of the Colorado Plateau. The Shinarump conglomerate covers approximately 75,000 square miles, contains vertebrate remains, and was presumably deposited during a period of quiescence in a semi-arid basin over which the coarse disintegration products from adjacent highlands were spread. The Moenkopi formation and the Chinle contain much bentonite (Allen, 1930, p. 283; Gregory and Moore, 1931, p. 57) and in color and manner of weathering greatly resemble the Brushy Basin-Buckhorn series. The Triassic-Jurassic boundary is involved in the upper part of this series just as the Jurassic-Cretaceous is in the Morrison.

The great masses of Eocene conglomerate usually termed Wasatch likewise indicate the destruction of mountains uplifted in the Laramide revolution. Volcanic ash is a common constituent of the fillings of the early Tertiary basins, and the widespread gravels and the products of volcanism again coincide with uplift and diastrophism. Vertebrate remains are also present.

The initial production of coarse boulder and pebble beds may be due to diastrophism, but their distribution over areas not immediately affected by uplift requires other agencies. Two broad classifications can be applied to continental gravel deposits: transported and residual. Both types and intermediate stages are usually present in any desert region. The transported type results from ordinary stream

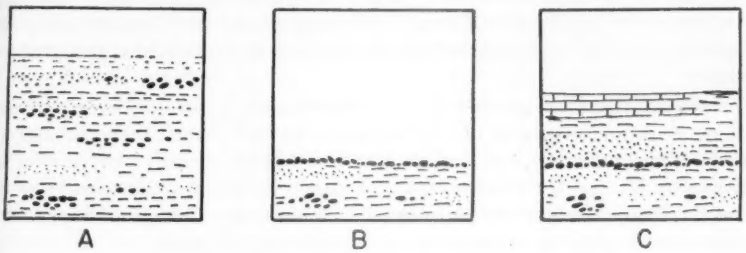

FIGURE 4.—*Development of desert armor*

A. Typical terrestrial sedimentary section.
B. Formation of desert armor by deflation.
C. Appearance in section after burial by other sediments. (Modified from Berkey and Morris, 1927, p. 334)

deposition or from torrential sheet floods, in which case the detritus is not concentrated in definite channels. Such deposits may be recognized by type of bedding, the effects of cut and fill, and the eroded surface on which they rest. The second or residual type of gravel results from the gradual lowering of the surface by weathering and removal of finer grains by solution or wind action. In arid regions the durable materials gradually concentrate to form the typical "desert armor" or "desert pavement". The usual characteristics of water-deposited materials are lacking.

Despite original inequalities a gravel deposit may become very evenly distributed by the wash of temporary streams, the action of rain and frost, and by deflation. Even a channel gravel may become widely disseminated if conditions are favorable and ample time is allowed.

The "desert pavement" type of deposit locally well developed in modern arid basins consists of a very thin veneer of durable rock types closely fitted into a mosaic. Despite the distinctive and striking horizontal aspect a cross section reveals nothing but a thin inconspicuous layer of pebbles between typical terrestrial sediments. Such a thin layer may represent a long time lapse, and the residuum of pebbles may have been concentrated from a considerable thickness of overlying beds, and yet the usual evidence of unconformity would be lacking, especially if materials similar to those below the "pavement" should in time cover and obscure it.

In the production of the Buckhorn and its equivalents the processes just outlined are considered to have been active. The more notable features of these conglomerates may be restated as follows: (1) great areal extent, (2) exceptional thinness, (3) a variety of bedding types, (4) very narrow zones of scattered pebbles, generally the so-called "gastroliths", (5) a similarity of overlying and underlying beds, and (6) no striking underlying unconformity.

These features fit into a paleogeographic situation approached by such modern

places as the Gobi desert but with no exact counterpart in the present. The drainage was evidently external, and the terrain approached a true plane not far above base level. The degree of aridity is problematical, but the area of deposition was probably desert-like in that vegetation was insufficient to prevent wind erosion on a large scale. Occasional torrential rainfall produced local sheet flooding with consequent rearrangement of the gravel cover. The gravel deposits were constantly replenished by erosion of the highlands to the west and southwest and were transported by slow stages eastward with consequent diminution of size and increase in roundness and polish.

As already noted the position of the conglomerates of the Buckhorn may vary through a vertical interval of 100 feet or more. In most places the concentration of pebbles is in one stratum, but in others several layers are present. All these irregularities may be expected where erosion was mainly by aeolian activity and sporadic sheet flooding. The existence of several lithologic facies in the Buckhorn and its equivalents indicates the existence of corresponding source areas.

In this reconstructed Morrison terrain the problem of origin of the so-called "gastroliths" may also find a solution. The evident lack of correlation between the majority of these stones and the remains of dinosaurs, their concentration in "stringers" and thin lenses, and above all their astounding local abundance all argue against a dinosaur origin. There are difficulties in any other theory, but the author believes the gastroliths originated as residual or lag gravels on an arid plain where wind blast was especially effective. The prevailing winds may have carried very fine volcanic ash composed of angular glass shards . . . now devitrified and altered to bentonite . . . but especially potent as abrasives at that time. Lack of faceting may be explained by a constant undermining and turning of the stones by various agents which prevented their fixation in a single position long enough for the production of definite facets. The author has examined many types of faceted and polished stones, including undoubted "gastroliths", and the nearest approach in polish, appearance, and composition to the "Morrison stones" are the so-called "Gobi stones" from the Asiatic Irdin Manha formation of Eocene age, which incidentally contains a mammalian fauna. Of the probable origin of this formation Berkey and Morris state (1927, p. 379):

> "It is probable that the Irdin Manha formation represents a rather dry flood plain, with trees or patches of wood along the courses of intermittent streams. Such a deposit suggests a semi-arid climate."

SOURCE OF BUCKHORN CONGLOMERATE

Study of the constituent pebbles of the Buckhorn conglomerate has clarified certain aspects of the paleogeography of the time of its formation.

The pebbles may be classified mainly as cherts, but many which outwardly resemble cherts are fine-grained quartzite, and others are silicified limestones. There are no pebbles of shale, limestone, sandstone, or other soft sedimentary rocks, and igneous rocks are extremely rare. Gray, black, yellow, and brown are the most common colors; red and white are occasionally found. The lighologic composition of the pebbles indicates a variety of source beds, mainly sedimentary rather than igneous bodies.

Most of the contained fossils are preserved entire, but many are simply external impressions. Most identifications cannot be carried beyond generic ranking. Fossils contained in the pebbles were identified by C. O. Dunbar, J. B. Reeside, Jr., R. S. Bassler, and J. B. Knight. The following summary indicates the relative abundance and age of the forms present:

BRYOZOA: This class is represented by many well-preserved specimens. R .S. Bassler who examined the fauna states that although most of the forms are new to him they resemble those of the Kansas Carboniferous but are on the whole more robust. The following genera are represented: *Amplexus*, *Rhombopora*, *Stenopora*, *Fenestella*, *Meekopora*, *Lioclema*, and *Polypora*. These are of Upper Paleozoic age, mainly Pennsylvanian and Permian.

BRACHIOPODA: The following brachiopods are present: *Chonetes sp.*, *Composita* cf. *C. arizonica*, *Strophalosia* cf. *S. hystrica* Girty, *Punctospirifer* (?) cf. *P. pulchra*, *Marginifera sp.*, *Spirifer sp.*, and some medium-sized productids of pre-Leonard aspect. These are likewise Upper Paleozoic.

PORIFERA: Although sponges from the pebbles are evidently undescribed, E. D. McKee, who has extensive first-hand knowledge of the rocks of the Grand Canyon region, has examined them and reports them to be identical in appearance with those found in great abundance in certain parts of the Kaibab formation (McKee, 1938, p. 155).

COELENTERATA: Most of the corals in the Buckhorn pebbles are also evidently undescribed species. The most abundant genus is *Syringopora* of which several distinct species occur, some with large and others with small tubules. Several zaphrentoid corals are present, as well as branching forms of undetermined affinity. The only really good guide is *Chaetetes milleporaceus*, which is very abundant; many pebbles composed entirely of this form must have come from rather large colonies. This fossil is considered a good guide to the Des Moines series of the Pennsylvanian.

ECHINODERMATA: Crinoid plates in some cases compose entire pebbles, but no diagnostic remains were found.

PROTOZOA: The best aids to specific age determination furnished by the pebbles are undoubtedly the fusulines. C. O. Dunbar has kindly furnished the following information:

"Two of the pebbles, numbers 4 and 5, are very certainly of Wolfcamp age and are filled with the characteristic *Pseudoschwagerina texana*, *Schwagerina hueconensis* and *S. franklinensis?*. In pebble 5 I can identify *Pseudoschwagerina uddeni*, *P. texana* and *Schwagerina thompsoni*. These species occur together in Hueco limestone of West Texas.

Pebble 2 may be from the same general horizon. It is filled with a single species which appears to be *Triticites uddeni*. I have compared it with the types of that species and I am unable to distinguish it from the Texas form without having better sections. *T. uddeni* is abundant in the lower part of the Wolfcamp and equivalent horizons in West Texas.

I am unable to make any satisfactory identifications from pebbles 3 or 7. Pebble 6 is filled with what appears to be a single species of quite distinctive form. It is a slender species of 6 or 7 volutions, attaining a length of probably 12 mm., and it is thinner at the middle than towards either end. This median constriction recalls *Schwagerina setum*, which occurs in the Bone Spring limestone of West Texas. Your specimens are similar in shape but only about half as large, and I think represent a distinct species. It appears to belong to the genus *Schwagerina* but is close to the stage of transition to *Parafusulina*. From this stage of evolution I judge it might occur high in the Wolfcamp horizon or possibly a little above this.

Pebble no. 1 includes a very slender, fusiform species of about 5 volutions, which attains a length of 10 mm. and a thickness of about 2.2 mm., and has deeply folded septa which seem in one section

to have distinct cuniculi. If so, however, they are very narrow. I would classify this as an undescribed species of *Parafusulina* but a very primitive one in that genus. It would be appropriate for a horizon low in the Leonard series.

Pebble 9 is filled with a single species very similar to *Triticites powwowensis*. That species also occurs in the Hueco limestone and is just about on the borderline between *Triticites* and *Schwagerina*. It may be the form which Needham described as *Schwagerina emaciata* var. *jarillaensis*. His specimens were from the Hueco limestone.

Pebble 8 is filled with a rather small species of *Triticites* with well-developed chomata. The preservation is so bad that I cannot get satisfactory sections for identification. I should expect it to belong in the Pennsylvanian."

GASTROPODA: Several gastropods are present, including low- and high-spired types. The only identifiable form is *Euomphalus sp.*

PELECYPODA: Imprints of a few unidentifiable pelecypods constitute the only indication of this group.

SCAPHOPODA: *Plagioglypta canna* is present in several pebbles.

In addition to these fossils there are abundant pebbles of black and brown petrified wood, evidently conifer, identical in appearance to the wood of the Chinle-Shinarump beds of Triassic age.

The age of the beds supplying the detritus in the Buckhorn is thus indicated as late Paleozoic and early Mesozoic. Definite Pennsylvanian and Permian types are present, as well as some which may be Mississippian. The Kaibab and other Permian formations must have contributed much detritus, and the thick Bird Springs limestone or its equivalents were also important contributors. The abundance of petrified wood suggests that the Triassic was also undergoing erosion. The silicified wood fragments are certainly the most durable fraction of the Chinle and Shinarump formations and the only parts capable of enduring long transport without disintegration.

The second phase of the problem is to discover the place of original deposition of the sediments which contained the cherts now included in the Buckhorn. The major drainage was most certainly from west to east, and the testimony of the pebbles themselves is that they originated in the west and were transported toward the east and northeast. Their average size decreases as the beds are traced farther from the Mesocordilleran geanticline. The distribution of the Buckhorn has a major axis from the southwest to the northeast as though along a major river system. The only other possible source is the Colorado Rockies, but if these played any important role there would be many pebbles of pre-Cambrian and Lower Paleozoic types (Heaton, 1933, p. 162). Igneous pebbles are exceedingly rare in the Buckhorn, but on the east side of the Colorado Rockies some pre-Cambrian detritus has been found in the Morrison, and this may have come from the Colorado Rockies.

The Buckhorn was therefore derived from Carboniferous and Permian rocks lying to the west and southwest. When this formation was deposited Triassic, Permian, and Carboniferous formations to the southwest and west were undergoing erosion. The disintegration of the limestones and shales produced considerable residual chert which upon uplift of the old surface was eroded and removed. The section at Currant Peak, Utah, suggests that, after this initial removal of residual siliceous material from the surface, erosion cut into the unweathered sediments below with a gradual decrease in chert and a corresponding increase in quartzite, sandstone, limestone, and shale being supplied to the agents of erosion.

FINAL PHASES OF TERRESTRIAL SEDIMENTATION

The Cedar Mountain shales above the Buckhorn conglomerate are so similar to the Brushy Basin that very possibly they were derived from reworked and transported Morrison. The unrest preceding the ingress of the upper Cretaceous sea produced local basins where various sediments, mainly shales, were deposited. These were brought in from the west and south and deposited over wide areas in the Rocky Mountain region.

Much detailed work is required before the chronology of these beds can be determined, but after the deposition of the Buckhorn, sedimentation was increasingly influenced by the development of the geosyncline which reached maximum importance later in the Cretaceous.

PROBLEMS OF CORRELATION AND NOMENCLATURE

GENERAL CONSIDERATIONS

Although Eldridge adequately defined the type section of the Morrison, it has been revised owing to the discovery of fossil material unknown to the original workers. The upper shale contains a flora of dicotyledonous plants found elsewhere with marine organisims of Washita age. As no distinct break separates this shale from the underlying "Saurian conglomerate" the latter has also been removed and made the base of the so-called "Dakota group". Lee (1920) advocated the removal of about 15 feet of sediment at the base of the type section on the basis of supposed marine Sundance fossils, later shown to be *Chara*-like algae and fresh-water mollusks of types common in the lower part of the Morrison (Reeside, 1931). With this lower part restored, the type section has been used as a basis for the correlations made in this paper, with the assumption that it represents the sediments accumulated after the withdrawal of the Logan Sea and before the close of the Jurassic. This somewhat arbitrary definition of the Morrison has been made to cover conditions observed over a wide area and has been useful in dealing with the formation as a whole. However, certain considerations indicate that new difficulties may arise which will necessitate a revision of the type section or an adjustment in the terminology of regions to the west and northwest. Reeside (1931) has shown that the lower part of the type section which contains algae is probably to be correlated with similar beds above the Entrada in many places in western Colorado. The marly beds of western Colorado referred to by Reeside are undoubtedly the Summerville and Wanakah equivalents discussed in this paper. McKnight (1940, p. 90) has traced the Curtis into basal Summerville in the Green River Desert.

Although verification of the various aspects of the above correlations is necessary, the taxonomic problems involved are fairly clear. If the type Morrison contains equivalents of the Curtis and Summerville formations, the San Rafael group would be invalidated, and this useful standard could not easily be dispensed with.

Several alternative methods of adjusting the terminology are evident: (1) revision of the type section of the Morrison to exclude those portions which are in conflict with other units; (2) creation of a Morrison group which would include the terrestrial equivalents of the marine San Rafael sediments.

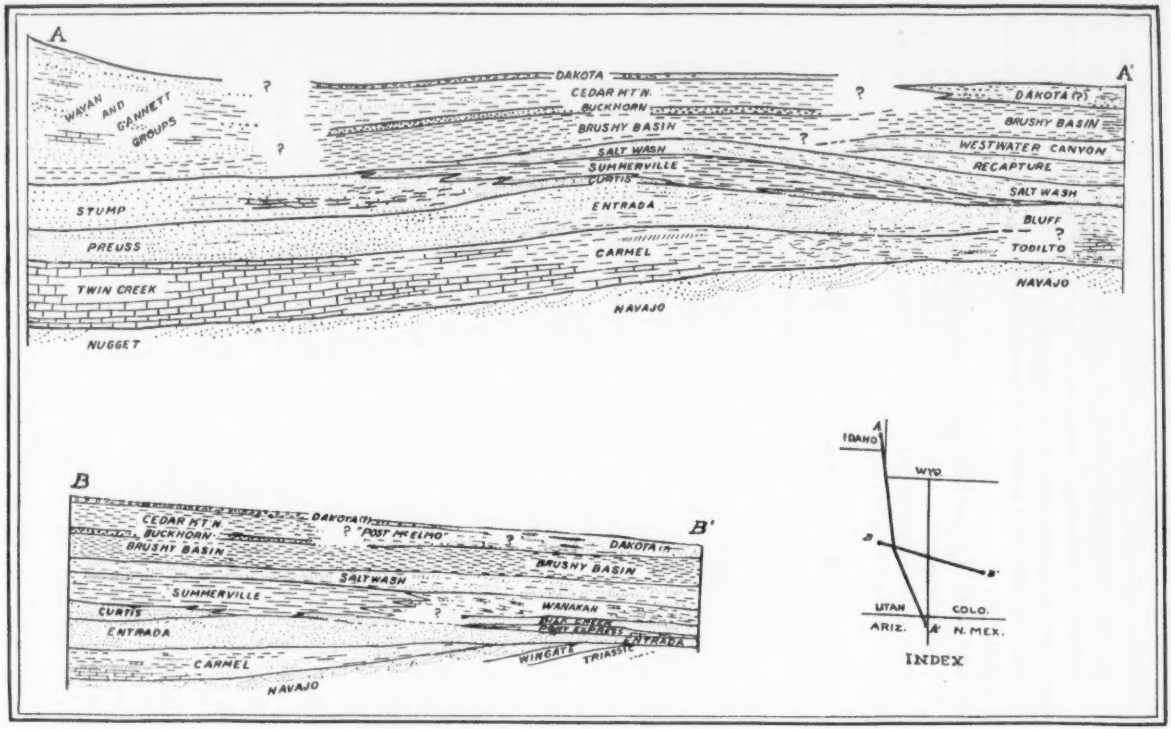

FIGURE 5.—*Restored sections of late Jurassic and early Cretaceous sediments*

Index map indicates positions of sections and their approximate lengths. Portions of sections where relationships are obscure or unknown are indicated by question marks. Vertical scale greatly exaggerated.

The difficulties are mainly concerned with nomenclature and can be solved more easily when additional evidence has been collected. The nomenclature of many units which have been included in the Morrison involves the broader problems of designating contemporaneous and interfingering marine and terrestrial equivalents. The shallowness of the Jurassic invasions and the flatness of the surrounding terrain favored almost continuous sedimentation under both subaqueous and subareal conditions and complex interfingering of resulting deposits. Playa lakes and shallow embayments of the sea were common, and slight changes of sea level shifted the strand line over wide areas.

The writer believes that each set of marine-terrestrial equivalents should be treated as a separate problem and that no general and fixed procedure can be followed. Where erosion has removed the areas of possible overlap or where overlying sediments conceal the questionable deposits the problem is simplified. Thus the great area of erosion adjacent to the Colorado River separates the fossiliferous facies of the Carmel and Curtis from nonfossiliferous equivalents to the east. The covered area of the Uinta Basin conceals the probable interfingering of Curtis and Summerville type sediments. The relationships of the Entrada and Carmel to the Todilto and of the Wanakah to the Summerville are confusing and not easily fitted into the usual scheme of nomenclature.

Although the taxonomy has been complicated by refinements of correlation a definite order is evident in the Jurassic and lower Cretaceous rock units over a very wide area. Continental as well as marine deposits show a surprising uniformity from place to place. The following tabulation summarizes the sedimentary types and the names applied to them in various places:

Lower Cretaceous (?)	
Fuson shale Cedar Mountain shale Post-McElmo beds (upper part) Gannett group (upper part) Cloverly shale Lower "Dakota" shale	Shale, drab to highly colored, generally gray, green, or light red. Somewhat bentonitic. Irregular in deposition but usually less than 150 feet thick. "Gastrolith"-bearing over wide areas. Derived from west and southwest.
"Saurian conglomerate" Buckhorn conglomerate Cloverly conglomerate Ephraim conglomerate Lower "Dakota" conglomerate Dakota sandstone Post-McElmo beds (lower part)	Conglomerate, composed of black cherts and jaspers. Coarser and thicker toward west. Very widespread but seldom over 50 feet thick. Originated as a combination of fluvial, residual, and lag gravels.
Upper Jurassic	
Brushy Basin shale Gannett group (lower part) Beckwith (lower part) Morrison (as typically developed over Rocky Mountain area and as in the upper portion of type section).	Shale, varicolored, bentonitic; minor amounts of sandstone and limestone. Well-preserved dinosaur remains—the well-known "Morrison fauna." Lacustrine and fluviatile origin. Salt Wash sandstone member in lower part in Colorado Plateau; Junction Creek sandstone in vicinity of San Juan Mountains.

Index map indicates positions of sections and their approximate lengths. Portions of sections where relationships are obscure or unknown are indicated by question marks. Vertical scale greatly exaggerated.

Middle La Plata Curtis Summerville Lower part of type Morrison (?) Stump sandstone Upper Sundance Pony Express limestone, Wanakah marl, and Bilk Creek sandstone	Shale and sandstone, marine in northern areas grading southward into lacustrine and terrestrial beds. Marine portions contain glauconite; *Belemnites densus*, typical guide fossil. Algal limestone and "ashy shales" occur in southern areas.
Entrada Preuss sandstone Bluff sandstone Jelm (of some authors) Lower La Plata (of some authors) Upper La Plata (of some authors) Sundance sandstone (in part) Exeter (of some authors) Lower McElmo (of some authors)	Sandstone, pink, salmon, brown, and white. Generally very smooth weathering. Thin-bedded and silty toward west but in eastern and southeastern areas displays aeolian cross-bedding.
Carmel Twin Creek Lower Sundance Todilto Ellis (in part)	Limestone, gypsum, shale, and sandstone. Marine in northern areas grading southward into littoral and continental beds. *Pentacrinus asteriscus*, typical guide fossil for marine portions.
Middle or Lower Jurassic Navajo Nugget Lower Ellis (?) Lower La Plata (of some authors)	Sandstone, yellow, white, pink, and brown. Massive, unfossiliferous, cross-bedded. Very thick in southwestern Utah, thinning to north and northeast.

TODILTO FORMATION

The writer hesitates to make suggestions regarding the Todilto since he has not seen the type section nor the exposures in northwestern New Mexico. However, a study of the literature and a consideration of regional relationships seem to justify the correlation of the Todilto complex with the lower part of the San Rafael group (Carmel) for the following reasons:

(1) Its occurrence below the Bluff sandstone (upper Entrada equivalent) in the Carrizo Mountains.

(2) The presence of abundant bedded gypsum which suggests an origin from marine waters such as would be supplied by the Carmel sea.

(3) The limestone beds, which, while not of marine origin, seem to be more closely related to the calcareous Carmel than to the more argillaceous Morrison.

(4) The contorted and crinkled bedding which is identical with that of the Carmel.

(5) The evidence of the fossils, though very weak, favors a Sundance age.

(6) The fact that the Carmel and Todilto are mutually exclusive in area.

The Todilto should probably constitute a distinct formation with the understanding that it includes many rock types and is equivalent to the lower part of the San Rafael group.

BLUFF SANDSTONE

The Bluff sandstone has been correlated with the Entrada by a few workers, but Baker, Dane, and Reeside as well as Gregory favor its inclusion in the Morrison. Goldman and Spencer suggest equivalence to the Junction Creek (upper La Plata). These various interpretations are due in part to the stratigraphic complications along the line of outcrops which follows Butler Wash, Cottonwood Wash, and Allen Canyon in San Juan County, Utah, and which connect with the exposures in Dry Valley. The typical Entrada of Dry Valley passes southwestward into Carmel-like lithology; a zone of red, thin-bedded shaly sandstone wedges into the Entrada, separating it into two parts—the upper, cross-bedded and smooth weathering the lower bright red and more evenly bedded. The Summerville thins from Dry Valley southward and near the junction of Butler and Comb washes disappears. The sandstones of the Salt Wash rest upon the Entrada southward to the Carrizo Mountains. Near the mouth of Allen Canyon there is no well-defined Entrada. Along Butler Wash the two facies appear as discontinuous lenses which thicken and thin along the strike. At several places the whole section is sandstone and looks like typical Entrada. As the San Juan River is approached the shaly portion becomes more prominent, and the upper sandstone is locally known as the Bluff. Thus the combined Entrada and Carmel present four types of sediments: (1) at the base, alternating shales and sandstones (the Carmel of Gregory), (2) a brick-red sandstone (Entrada of Gregory), (3) a sequence of thin-bedded shales and sandstones (the Summerville of Gregory); (4) the Bluff sandstone.

This is the only continuous line of outcrops available for tracing the San Rafael group into the Four Corners area. The isolated exposure of Entrada near Verdure at the mouth of Devils Canyon is similar to the exposures in Dry Valley. The outcrops in McElmo Canyon which are not connected with those at Bluff can be interpreted in several ways and should be studied more carefully. The Bluff can be traced through the Gothic Mesas area into the Carrizo Mountains where it thins considerably and is replaced by more evenly bedded sediments.

These sequences indicate, in the writer's opinion, that the Bluff is equivalent to the upper portion of the Entrada and should not be included in the Morrison. The term Bluff may be useful in designating a facies of the Entrada or it may be discarded, depending on its future usefulness.

PONY EXPRESS LIMESTONE, BILK CREEK SANDSTONE, AND WANAKAH MARL

The Pony Express limestone, Bilk Creek sandstone, and Wanakah marl have been studied and discussed by Goldman and Spencer (1941). Although these units were classified as members of the Morrison, Spencer and Goldman state:

> "... We believe Pony Express limestone and Bilk Creek sandstone are equivalent to the Curtis formation of Utah; Wanakah marl is equivalent to Summerville formation. ... However introduction of this new classification would involve redefinition of Morrison in parts of Utah, New Mexico and Paradox Valley region of western Colorado. ... Consequently, present classification of these beds as Morrison is here retained, pending completion of mapping in certain critical areas." (p. 1745, footnote to Fig 4.)

The writer believes that the correlations suggested by Spencer and Goldman can safely be made and that the retention of these units as members of the Morrison is no

longer justified. Since the Pony Express limestone and the Bilk Creek sandstone cannot be traced into the Curtis and as they differ from it in lithology, absolute equivalence would be difficult to prove. On the other hand, these units cannot properly be included in the Morrison and should constitute independent formations, older than Morrison and younger than Entrada—perhaps equivalent to Curtis and lower Summerville.

The Wanakah marl probably grades into the Summerville and into the marly beds of northwestern Colorado. In this case a definite boundary will be difficult or impossible to draw, and workers in any area of possible overlap must rely on lithologic peculiarities and reference to type sections in mapping or describing this portion of the sequence. Color may be useful; the Summerville is generally dark red or brown, while the Wanakah is gray, green, or light red. The thin bedding of the Summerville is characteristic. The calcareous nature of the Wanakah contrasts with the sandy or shaly Summerville. The differences in lithology seem to justify the retention of both units as distinct formations even though there are areas of conflicting characteristics.

SALT WASH SANDSTONE, RECAPTURE SHALE, AND WESTWATER CANYON SANDSTONE

The Salt Wash, Recapture, and Westwater Canyon members of the Morrison formation consist of alternating soft shales and drab sandstones and differ from each other only in details of lithology and manner of weathering. The Recapture and Westwater Canyon insofar as known, have only a limited distribution in the general area of the Four Corners, but the Salt Wash covers a much larger territory.

None of these members has been traced into marine beds, and the sedimentary features as well as the contained fossils point to a terrestrial origin. Different source areas are suggested for each member, but the environment of deposition was such that the sedimentary features are very similar. Under the definition of Morrison used in this paper all are accepted as members of that unit.

Workers who have correlated the Salt Wash with the Bluff have made one of the several possible interpretations of exposures along the east flank of Comb Ridge, but the absence of vanadium deposits in the Bluff and their consistent presence in the Salt Wash (lower part of Gregory's Recapture) are strong evidence against this correlation. Gregory's suggestion that the Westwater Canyon and the Salt Wash are equivalent was tentative only and has not been verified by the present study.

The Salt Wash is the first terrestrial deposit formed after the complete withdrawal of the sea. It has not been possible to trace it into marine beds. Its relationships with the Morrison favor retaining it as a member of that formation. Although nothing similar to the Salt Wash can be found at the type locality of the Morrison, in the Uinta Mountains, or in the Morrison of Wyoming and Montana, it is practically coextensive with the more typical "variegated shales" over the area here treated. Its lower boundary, therefore, becomes the base of the Morrison and although it is gradiational in many places it is generally usable for mapping. In areas north of the Uinta Mountains the base of the Morrison is usually drawn at the top of the Curtis or its equivalents where there is a fairly distinct break in lithology, fossil content, and color. Just where the Salt Wash fits into the Morrison of the Uinta

Mountains has not been determined, but it probably corresponds to the sandy layers near the base.

BRUSHY BASIN SHALE

Most observers have commented on the division of the Morrison into two portions —an upper part, mainly of varicolored shale (Brushy Basin), and a lower sandstone part (Salt Wash). The Brushy Basin shale member is the only portion of the beds heretofore called Morrison west of the Front Range which can be correlated confidently with the type section at Morrison, Colorado. It is the only portion from which adequate fossil material for correlation has been collected, and it is identical in lithology and composition with the type section. The terms "variegated shale" and "joint clays" used so often in speaking of the Morrison are best applied to this unit. Its variability in color, bedding, lithology, and composition is more striking than any other portion. The term Morrison was brought into eastern Utah by Gilluly and Reeside during their investigation in the San Rafael area where the formation is mainly shale. They cite Riggs' finding of dinosaurs in the Grand River Valley as paleontological evidence for correlation. The deposits at the Dinosaur National Monument in the Uinta Mountains have since been accepted as part of the Morrison, and the paleontological reasons for extending the term westward seem sound.

The paleogeographical interpretation indicates that the final filling of the Jurassic basin and the aggradation of a vast plain were completed with the deposition of the Brushy Basin shale which covered all older deposits and probably buried even the remnants of the Colorado Rockies. The extreme flatness of the terrain in the late Jurassic and the part played by volcanic ash in the building of this deposit suggest that it is essentially contemporaneous throughout. The term Brushy Basin shale is practically synonymous with the Morrison, but where the second member, the Salt Wash sandstone, is present it can be used to indicate the division of the formation.

CEDAR MOUNTAIN GROUP

The upper boundary of the Morrison has long been in dispute. Since the earliest investigators in the Rocky Mountain region sought to delimit the Jurassic and Cretaceous there has been a thin sequence of beds of debatable status, placed first in one and then in the other of the major series. These beds were first included in the "Dakota" and with it constituted the "Dakota group", but later workers have placed them mainly with the Jurassic and have drawn the major line beneath the so-called "Dakota sandstone" which in itself is not everywhere consistent. In central, eastern, and northern Wyoming, central and northern Montana, and part of the Front Range area of Colorado the Cloverly formation occupies this interval. In western South Dakota, northeastern Wyoming, and southeastern Montana the term Inyan Kara group has been proposed for a similar sequence (Rubey, 1930, p. 5). In general the Cloverly and Inyan Kara are similar in that they are both divisible into three parts: (1) a lower chert conglomerate or sandstone; (2) varicolored shales much like the Morrison beneath; and (3) an upper sandstone sometimes called

"Dakota". A second sandstone may occur in unit 2. The Inyan Kara group includes the same beds as were formerly included in the Fall River sandstone, the Fuson formation, and the Dakota sandstone. Lee (1927) has traced the Cloverly beds over wide areas of Colorado and Wyoming and has shown the existence of rocks similar to the Cloverly overlying the true Morrison at the type section of the latter. Both the Inyan Kara and Cloverly are designated as Lower Cretaceous, but the paleontological evidence is not conclusive for all members.

Although the writer does not advocate the strict equivalence of these beds over such wide areas the occurrence of such a similar set of deposits is indeed striking, especially since an identical sequence of beds above the Morrison and below the Upper Cretaceous is present over most of the area here described. The common feature over all this wide region is the dark chert conglomerate separating the Morrison from the upper varicolored shales. Were it not for this thin but persistent stratum of conglomerate all the varicolored shales would be classed as Morrison. The inconspicuousness of this bed in many places has led investigators of small areas to disregard it, and it is only when a wide region is considered that it assumes importance. A careful search of the literature shows that many geologists have noted it, and their records are given here to supplement the observations of the present author.

Eldridge (1894, p. 6) reports for the Anthracite-Crested Butte area:

"The conglomerate at the base of the quartzite (Dakota) is usually 2 to 5 feet thick. A second fine-grained conglomerate whose pebbles are variously colored cherts and jaspers, occurs below this, separated from the quartzite by a stratum, sometimes 50 feet thick of greenish clays resembling those of the Gunnison formation to which they may belong."

Of the La Plata district, Cross and Spencer (1899, p. 4) say:.

"The lithologic similarity between the McElmo and Dakota formations is emphasized by a conglomerate containing white and dark quartz pebbles as much as one inch in diameter occurring frequently at 50 or 60 feet below the basal conglomerate of the Dakota, this lower stratum is sometimes 10 to 15 feet thick."

Coffin (1921, p. 90) gives the following for southwestern Colorado:

"The conglomerate which exists near the top of the McElmo formation is characterized by dense green pebbles. This McElmo conglomerate is normally separated from one in the overlying formation by a series of sandstones and green shales which range in thickness from a few inches to 100 feet. The upper one of these two beds is so consistently brown that for purposes of field work they were termed the "white conglomerate" and the "brown conglomerate."

For the San Rafael Swell, Gilluly and Reeside (1928, p. 81) state:

"In the northern part of the San Rafael Swell a persistent conglomerate from 3 to 40 feet thick containing many rounded pebbles of black chert occurs about 250 to 300 feet below the top, (of the Morrison) but it was not observed as a continuous bed either to the south or to the east. Lenses of similar conglomerates however recur to the east, though not at a consistent horizon."

Gale (1910, p. 60), observed in northwestern Colorado and northeastern Utah:

"As mapped by older surveys it (the Dakota) also included some varicolored shales similar to those of the underlying Jurassic beds. The reason for this inclusion was that a second and in many places a most prominent zone of sandstone and conglomerate strata was commonly found below the first occurrence of varicolored shale, and the whole was naturally classed together as a single formation included between overlying and underlying soft clay shale formations."

White's report on northwest Colorado in Hayden's Survey for 1876 (p. 29) states:

"The lower portion (of the Dakota) having a thickness of 300 (sic) feet consists of a dark-colored, coarse, siliceous pebble conglomerate, which is somewhat irregularly bedded and easily disintegrated. The upper portion, having a thickness of from 150 to 200 feet consists of a yellowish or brownish, rough, heavy-bedded sandstone, between which and the conglomerate some variegated bad-land sandstones usually exist . . . the bad-land strata of this group may be easily mistaken for those of the Jurassic."

Mansfield and Roundy (1917, p. 82) in speaking of the Ephriam conglomerate of southeastern Idaho (here correlated with Morrison) state:

". . . Perhaps 100 feet above the base there is an olive-yellow band 25 feet or more thick, in which the pebbles are almost exclusively of dark chert rounded or subangular and generally an inch or less in diameter."

The above quotations are given only to verify the fact of occurrence; the author takes the responsibility for the interpretation and correlation here presented. As already indicated, the Cloverly and the Inyan Kara group are considered Lower Cretaceous. The beds here discussed have yielded no distinctive fossils except those reported from the Peterson limestone above the Morrison in southeastern Idaho (Peck, 1940) which are favorable to a Lower Cretaceous age assignment. The paleontological evidence is weak, but structural and paleogeographical considerations strengthen the contention that the Jurassic ended with the deposition of the widespread Buckhorn conglomerate and its equivalents. Lammers (1939) has advocated a similar conclusion regarding the Cloverly conglomerate, but his interpretations differ somewhat from those presented here.

It is here recommended that the Buckhorn and the Cedar Mountain shales be called the Cedar Mountain group and tentatively classed as Lower Cretaceous.

OTHER CORRELATIONS

The relationships of the Morrison formation to such deposits as the Gannett group, the Beckwith formation, and the Arapien shale have been briefly discussed. As yet the correlations to be made are not fully indicated by field evidence. The more or less tentative conclusions made in this paper are as follows:

(1) The Morrison is to be correlated with the lower part of the Gannett group and to the equivalent part of the Beckwith where that formation is recognized.

(2) The Arapien shales probably include equivalents of the entire San Rafael group as well as the Morrison. The transition to the Indianola group probably corresponds to the break at the top of the Brushy Basin shale but may be at the base of the "Dakota."

(3) The Kelvin conglomerate includes equivalents of the Buckhorn, Cedar Mountain, and "Dakota." As it is marginal and composed mainly of clastics it probably cannot be recognized any great distance from the type locality. It probably corresponds to the thick conglomerate-shale sequence in the Currant Peak area.

(4) The "terra-cotta beds" near Coalville are above the Kelvin and seem to be more closely related to the Cretaceous sediments than to the Jurassic. They may have been deposited in restricted areas before the beginning of the true marine Upper Cretaceous typified by the Mancos, Aspen, and Frontier. Since beds similar to the

"terra-cotta" are found in the Currant Peak section and near Peoa they may be important enough to constitute a new formation, but evidence for this was not obtained. Other localities near the margin of the Cretaceous geosyncline exhibit beds evidently older than the first marine Cretaceous but younger than the typical Morrison. The beds near Tropic and Cannonville in the Kaiparowits region which have been called Morrison are very unlike anything seen elsewhere in that formation and are probably younger.

(5) The "Post-McElmo" beds of Coffin are probably equivalent to the Cedar Mountain shales.

(6) Beds called Dakota (?) may be of lower Cretaceous age in some places.

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Manuscript Received by the Secretary of the Society, June 4, 1942.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 55, PP. 993-1004, 1 PL. AUGUST 1944

CORRELATION OF THE CAMBRIAN FORMATIONS OF NORTH AMERICA

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CONTENTS

	Page
Introduction	993
Annotations	995
References cited	1000

ILLUSTRATION

Plate	Facing page
1. Correlation of the Cambrian formations of North America (Chart 1 of series)	1004

INTRODUCTION

This is Number 1 of the series of correlation charts of North American sedimentary formations in preparation by the Committee on Stratigraphy of the National Research Council, with the co-operation of other American stratigraphers (Dunbar, Carl O., *et al.*, 1942). The Cambrian Subcommittee of that Committee records here its thanks for the assistance which it has received from these friends, who have generously supplied much invaluable unpublished information.

The Cambrian chart has been especially difficult to prepare because of the incompleteness of our knowledge of the stratigraphy and faunas of the Cambrian rocks of some parts of this continent. To make it even reasonably complete and accurate it has been necessary for some of the members of the Cambrian Subcommittee to spend many months in field and laboratory work on previously little known sections and unstudied faunas. Some of this work has been made possible by generous grants from the Geological Society of America, grateful acknowledgment of which is made herewith.

The concerted and intensive scrutiny of the Cambrian faunas of North America which has been made in the course of this work has resulted in numerous revisions of, and additions to, our ideas concerning the faunal succession of that period and the correlation of formations in different parts of the continent. So many new genera of trilobites, which are the best index fossils in Cambrian rocks, have been described in the course of the preparation of the chart, and so many previously described genera have been found in regions where they had not been known to be present, that it seems desirable to record here for the information of the reader some of the more characteristic genera of each of the faunal zones.

Some genera range through more than one of these faunal zones, and some of the

zones can be identified not by the presence in them of a single genus or species that is restricted to that particular zone, but only by the presence in the zone of two or more genera that are found in association in that zone only. Our present imperfect knowledge of the Cambrian faunas of North America has necessitated this method of naming the faunal zones. No Cambrian zone or subzone is known to be characterized by a single species throughout all North America. Those zones and subzones for which a single species is named as the characteristic fossil are either known to be represented by fossiliferous strata in only a part of the continent or are believed to be represented by such strata in other parts of North America only because those other strata contain several genera of trilobites which were found associated with the characteristic species of that zone or subzone in the region where that species occurs.

Plethopeltis zone: *Plethopeltis, Plethometopus, Tellerina, Bowmania.*

Saukiella subzone: *Saukiella, Dikelocephalus, Saukia, Tellerina, Plethopeltis, Stenopilus, Euptychaspis.*

Calvinella subzone: *Calvinella, Dikelocephalus, Eurekia, Corbinia, Stenopilus, Plethometopus, Euptychaspis, Triarthropsis, Bowmania, Entomaspis.*

Upper *Dikelocephalus* (*D. gracilis*) zone: *Dikelocephalus, Saukia, Tellerina, Saukiella, Illaenurus, Eurekia, Corbinia, Stenopilus, Plethometopus, Euptychaspis, Triarthropsis, Acheilops, Bowmania, Entomaspis.*

Platycolpus-Scaevogyra zone: *Platycolpus, Plethopeltis, Plethometopus, Eurekia, Saukiella, Dikelocephalus.*

Dikelocephalus postrectus zone: *Dikelocephalus, Saukiella, Illaenurus, Prosaukia, Monocheilus.*

Briscoia zone: *Briscoia, Parabriscoia, Chuangiella, Prosaukia, Monocheilus, Platycolpus.*

Prosaukia subzone: *Prosaukia, Ptychaspis, Idahoia, Wilbernia, Pseudagnostus, Monocheilus, Chariocephalus, Irvingella, Briscoia.*

Ptychaspis subzone: *Ptychaspis, Wilbernia, Psalaspis, Idahoia, Monocheilus, Pseudagnostus, Litagnostus, Ellipsocephaloides.*

Taenicephalus subzone: *Taenicephalus, Parabolina, Conaspis, Kendallia, Stigmacephalus, Stigmacephalus* (*Maustonia*), *Litagnostus, Pseudagnostus, Wilbernia.*

Eoorthis subzone: *Stigmacephalus*(*Maustonia*), *Kendallia.*

Ptychopleurites zone: *Ptychopleurites, Irvingella, Berkeia, Deadwoodia.*

Elvinia zone: *Elvinia, Pseudagnostus, Glyptagnostus, Homagnostus, Irvingella, Burnetia, Camaraspis, Acrocephalites, Cheilocephalus, Pterocephalia, Berkeia, Dunderbergia, Housia, Dokimocephalus.*

Alphelaspis zone: *Aphelaspis, Raaschella, Blountia, Pseudolisania, Glyptagnostus.*

Crepicephalus zone: *Crepicephalus, Holcacephalus, Meteoraspis, Tricrepicephalus, Menomonia, Blountia, Blountiella, Komaspidella, Weeksina, Dresbachia, Lonchocephalus, Coosia, Coosella, Uncaspis, Terranovella, Kingstonia, Maryvillia, Llanoaspis.*

Cedaria zone: *Cedaria, Brassicephalus, Talbotina, Holcacephalus, Bynumia, Meteoraspis, Coosia, Lonchocephalus, Terranovella, Dresbachia, Maryvillia, Tricrepicephalus, Norwoodia, Menomonia, Blountia, Norwoodella, Kingstonia, Arapahoia,*

Coosella, Genevievella, Avonaspis, Ankoura, Cedarina, Proagnostus, Kormagnostus, Oedorhachis, Agnostus.

Deissella—Centropleura vermontensis zone: *Deissella, Centropleura, Spinagnostus, Grandagnostus, Paradoxides, Solenopleura, Palella, Albansia, Micragraulos, Dolichometopus, Anomocare, Conoides, Eteraspis, Kormagnostus, Blainia, Olenoides.*

Palella—Thomsonaspis zone: *Palella, Thomsonaspis, Paradoxides, Anomocare, Brachyaspidion, Eteraspis, Kochaspis.*

Olenoides—Marjumia zone: *Olenoides, Marjumia, Orria, Paradoxides.*

Elrathiella—Triplagnostus subzone: *Elrathiella, Triplagnostus, Parehamania, Rowia, Paradoxides, Bathyuriscus.*

Clappaspis subzone: *Clappaspis, Elrathiella, Elrathina, Kootenia.*

Bolaspis—Glyphaspis zone: *Bolaspis, Glyphaspis, Ehmania Amecephalus, Dawsonia, Elrathina, Kootenia.*

Glossopleura—Kootenia zone: *Glossopleura, Kootenia, Acrocephalops, Solenopleurella.*

Zacanthoides—Anoria zone: *Zacanthoides, Anoria, Dawsonia, Kootenia, Strotocephalus, Clavaspidella.*

Albertella zone: *Albertella, Kochina.*

Kochaspis liliana zone: *Kochaspis.*

Syspacephalus zone: *Syspacephalus, Inglefieldia, Kochiella.*

Olenellus zone: *Olenellus, Paedumias, Wanneria, Bathynotus.*

Bonnia zone: *Bonnia, Bonniella, Olenellus.*

Obolella zone: No trilobite genera; brachiopod genus *Obolella* common.

ANNOTATIONS

The formations in each column are so arranged that each fauna found in them is represented by a dot placed opposite the faunal zone with which this fauna has been identified. When a fauna is known to be present in a formation, but there is some doubt as to its true faunal zone, a question mark is placed beside the dot. Where the fauna is one which is characteristically found in the North Atlantic region (northeastern North America and northwestern Europe) a triangle, instead of a dot, is used to indicate its presence.

Solid horizontal lines between formations indicate that the boundaries between the formations are known; broken lines indicate that the exact position of the boundary is not known. Wavy lines indicate the presence of stratigraphic breaks. The absence of beds in a section is indicated by parallel perpendicular lines. No attempt has been made to indicate in any way on the chart the actual or relative thicknesses of the various formations.

Numbers on some of the sections refer to the following special notes relating to the formations.

1. Two subfaunas can be recognized in this zone in western North America—an upper one containing several undescribed genera of trilobites, some of which range into the Upper Cambrian, and a lower one holding undescribed species of *Deissella* and other undescribed genera of trilobites. Denson has just completed a study of

these two subfaunas, the results of which will be published soon. A number of Chinese and North Atlantic genera, previously not known to exist in western North America, have been found by Denson in the *Deissella* and *Thomsonaspis* zones of Utah, Wyoming, and Montana. Of these genera, those occurring in the North Atlantic region are found there in the *Paradoxides forchhammeri* and *Paradoxides davidis* faunas.

2. The *Syspacephalus* fauna occurs in an unnamed formation underlying the Cadiz formation in the Marble Mountains, California (Mason and Hazzard, unpublished).

3. The *Nevadia* fauna of California is probably older than the *Olenellus* fauna, but how much older is not known.

4. It is now believed by Noble and Mason that the Johnnie formation and Noonday dolomite, which were placed in the Lower Cambrian by Hazzard, are pre-Cambrian.

5. These faunas have not been differentiated in the field in this section.

6. An undescribed fauna, somewhat younger than the other *Deissella-Centropleura vermontenesis* faunas, occurs near the top of the Bloomington formation. It will be discussed in a paper by Denson which is to be published soon.

7. Faunas of both the *Albertella* zone and the *Kochaspis liliana* zone are present in the *Ptarmigania* beds.

8. In the Pend Orielle district, Idaho, an unfossiliferous quartzite, the Gold Creek quartzite, is overlain by the Rennie shale holding *Elrathia* and *Glossopleura*, and that shale is followed by the Lakeview limestone containing *Alokistocare*, *Clavaspidella*, and *Elrathia*. Resser (1938b) compares the Rennie fauna with faunas in the Ptarmigan formation and correlates the Lakeview limestone with the Spence shale.

9. This fauna is older than the *Deissella-Centropleura vermontensis* fauna. It may be of the same age as the *Thomsonaspis* fauna or it may be somewhat younger.

10. *Clappaspis* is the characteristic genus of this fauna.

11. Unstudied fauna similar to that of the Damnation formation.

12. The Cambrian sequence in northeastern Washington has been described recently by Park and Cannon (1943). They recognize three formations which are, in ascending order, the Gypsy quartzite, the Maitlen phyllite, and the Metaline limetone. The sequence is of Lower and Middle Cambrian age, and no Upper Cambrian formations are known here. The Gypsy quartzite carries unidentifiable trilobite fragments; a limestone band near the base of the Maitlen phyllite has yielded fragmentary specimens of *Archeocyathus*, and because of this the Gypsy and part of the Maitlen are considered to be of Lower Cambrian age. The Metaline limestone carries a fauna characteristic of the Stephen formation, including such genera as *Elrathia*, *Neolenus*, *Kootenia*, and *Pagetia*, and is classed as Middle Cambrian. It is overlain unconformably by Ordovician shales of Normanskill age. The fossils were identified by Bridge.

13. Kobayashi (1938) has recorded from the Brisco-Dogtooth area, British Columbia, faunas containing *Crepicephalus*, *Elvinia*, *Parabolinella*, *Irvingella*, *Plethopeltis*, *Taenicephalus*, and other Upper Cambrian genera.

14. Undescribed fauna of late Middle Cambrian aspect, probably in the *Palella-Thomsonaspis* zone.

15. The stratigraphic position of the *Ogygopsis* shale is uncertain. Some workers

have placed it in the Stephen formation, others consider it to be of the age of the Eldon formation.

16. Lower and Middle Cambrian faunas have been found in the Mackenzie Valley, but the Cambrian stratigraphy of that part of northwestern Canada has not yet been carefully studied.

17. The right half of this column roughly represents the eastern side of the uplift, the left half represents the western side.

18. The left half of this column represents the northern side of the uplift, the right half represents the southern side.

19. The dots on the left side represent faunas found in the Wichita Mountains, those on the right side are faunas found in the Arbuckle Mountains.

20. The *Osceolia* fauna has recently been found in Wisconsin in beds of the Arcadia member of the Trempealeau formation, between the *Platycolpus-Scaevogyra* beds of the St. Lawrence member of the Trempealeau formation and the *Dikelocephalus postrectus* beds of the Bad Axe member of the Franconia formation. This *Osceolia* fauna thus takes its place as a distinct new unit in the Wisconsin-Minnesota faunal succession. As correlations of the Arcadia member with formations elsewhere in North America have not yet been made, no *Osceolia* zone or Arcadia member have been included in the chart, although it may have to be inserted in future editions. *Osceolia* is the characteristic genus of the Arcadia member and, as far as known, is restricted to that member.

21. A fauna containing the genus *Proaulacopleura*, which appears to be closely related to *Olenus*, and the genus *Glyptagnostus*, which occurs in association with *Olenus* in Scandinavia, is present at Cedar Bluff, Alabama.

22. An upper Middle Cambrian fauna occurs in the Conasauga formation at Livingston, Georgia, but its exact age is not known. It may belong in the *Deissella-Centropleura vermontensis* zone.

23. Position of the Brierfield, Ketona, and Bibb according to unpublished data by Bridge, Cloud, and Denson. A Middle Cambrian fauna occurs in the top of the Conasauga formation as it is represented at several localities near Montevallo, Alabama (Butts, 1926, p. 73).

24. The Weisner quartzite rests unconformably on the Wash Creek slate of pre-Cambrian age.

25. According to U. S. Geological Survey usage, the Lower Cambrian includes also the Hampton shale and the Unicoi formation. The latter unconformably overlies pre-Cambrian volcanics and older gneisses.

26. According to U. S. Geological Survey usage, the Lower Cambrian includes also the underlying Harpers shale, Weverton quartzite, and the Loudoun formation. The latter unconformably overlies pre-Cambrian volcanics and older gneisses.

27. The Frederick limestone is known only in Frederick Valley, Maryland, where it rests unconformably on the Antietam quartzite. In Frederick Valley the base of the Antietam is not exposed.

28. In southeastern Pennsylvania the Ledger dolomite is unconformably overlain by the Conestoga limestone, the lower part of which may be equivalent in age to the Frederick limtestone.

29. According to U. S. Geological Survey usage, the Lower Cambrian includes also the underlying Harpers shale and Chickies quartzite (with basal Hellam conglomerate member). The latter rests unconformably on pre-Cambrian volcanics and older gneisses.

30. The Hardyston formation, which is recognized also in eastern Pennsylvania, is stratigraphically continuous into the highlands of southeastern New York, where it is known as the Poughquag quartzite. The Poughquag quartzite is overlain by the Wappinger limestone, the lower part of which includes both Lower and Upper Cambrian equivalents.

31. The *Centropleura vermontensis* fauna of Vermont includes some genera of trilobites which occur in the *Paradoxides forchhammeri* faunas of Europe and also other genera of trilobites which are present in the "Park" faunas of the Rocky Mountains.

32. Probably either upper Middle Cambrian or lower Upper Cambrian.

33. The exact age of the *Agnostus pisiformis* faunas has not yet been determined. They may be a little older than is here indicated.

34. Believed by Resser to be younger than here indicated.

35. The Cambrian faunas of northern and western Newfoundland resemble faunas which are known to occur elsewhere in North America only west and southwest of Newfoundland except for the Devils Cove fauna, which is known elsewhere only in southeastern Newfoundland, eastern Massachusetts, and Europe.

36. The fauna of the Bastion formation contains some genera which are found also in southeastern Newfoundland and northwestern Europe and other genera which occur also in southeastern and western North America.

37. Data for this column were drawn from the following sources: Bridge (1937), Deiss (1939b), Howell and Mason (1938), Howell and Lochman (1939), Howell and Duncan (1939), Resser (1933; 1938b), Resser and Howell (1938), Raasch (1935), and Twenhofel, Raasch, and Thwaites (1935).

38. Data for this column derived from Mason (1935), Hazzard and Mason (1936), Mason (1938), and Hazzard (1938).

39. Data for this column derived from C. E. Resser and E. D. McKee, unpublished.

40. Data for this column derived from Schenk and Wheeler (1942).

41. Data for this column derived from Stoyanow (1936; 1942) and Wheeler and Kerr (1936).

42. Data for this column derived from Wheeler and Lemmon (1939), and J. Bridge, J. F. Mason, and N. M. Denson, unpublished.

43. Data for this column derived from Mason, Longwell, and Hazzard (1937) and Mason (1938).

44. Data for this column derived from Mason (1938), Deiss (1938), and Wheeler (1940).

45. Data for this column derived from Walcott (1908), Deiss (1938), and D. C. Duncan, unpublished.

46. Data for this column derived from Walcott (1908), Deiss (1938), Williams and Maxey (1941), and C. E. Resser, Charles Deiss, and D. C. Duncan, unpublished.

47. Data for this column derived from Miller (1936) and Christina Lochman and N. M. Denson, unpublished.

48. Data for this column derived from Miller (1936), Deiss (1938), and Christina Lochman and N. M. Denson, unpublished.

49. Data for this column derived from Dorf and Lochman (1938), Dorf (1934), and Howell and Lochman (1936).

50. Data for this column derived from Deiss (1936), Howell and Duncan (1939), and Christina Lochman, unpublished.

51. Data for this column derived from Deiss (1936), Howell, Lochman, and Duncan (1938), and B. F. Howell and N. M. Denson, unpublished.

52. Data for this column derived from Deiss (1939b) and N. M. Denson, unpublished.

53. Data for this column derived from Walcott (1928), Deiss (1938; 1940), and N. M. Denson, unpublished.

54. Data for this column derived from C. D. Walcott, various papers in Smithsonian Miscellaneous Collections, checked by C. E. Reeser.

55. Data for this column derived from C. E. Resser, J. Harlan Johnson, B. F. Howell, and D. C. Duncan, unpublished.

56. Data for this column derived from Mertie (1930) and C. E. Resser, unpublished.

57. Data for this column derived from Bridge (1937) and Lochman (1938), and Bridge and V. E. Barnes, unpublished.

58. Data for this column derived from Bridge (1936), Frederickson (1941), and J. Bridge, Christina Lochman, G. O. Raasch, and E. A. Frederickson, unpublished.

59. Data for this column derived from Meyerhoff and Lochman (1934; 1935; 1936).

60. Data for this column derived from Dake (1930), Bridge (1937), Ulrich, Foerste, and Bridge (1930), and Lochman (1940).

61. Data for this column derived from Ulrich and Resser (1930), Twenhofel, Raasch, and Thwaites (1935), Raasch (1935; 1939), and G. O. Raasch, unpublished.

62. Data for this column derived from Butts (1926), Resser (1938a), and C. E. Resser and E. O. Ulrich, unpublished. Also J. Bridge, P. E. Cloud, and N. M. Denson, unpublished.

63. Data for this column derived from Hall and Amick (1934), Oder (1934) and Resser (1938a; 1942). Also J. Bridge, unpublished.

64. Data for this column derived from Ulrich (1911), Resser (1938a), and C. E. Resser, unpublished, and J. Bridge, unpublished.

65. Data for this column derived from Resser (1938a) and C. E. Resser and J. Bridge, unpublished.

66. Data for this column derived from Ulrich (1911), Resser (1938a), and Resser and Howell (1938).

67. Data for this column derived from Jonas and Stose (1936).

68. Data for this column derived from Weller (1903), Howell (1942), and B. F. Howell, unpublished.

69. Data for this column derived from Ruedemann (1930), Wheeler (1942), and Christina Lochman and B. F. Howell, unpublished.

70. Data for this column derived from Schuchert (1937), Raymond (1937), Howell (1937), and B. F. Howell, Christina Lochman, and D. C. Duncan, unpublished.

71. Data for this column derived from Shaler and Foerste (1888), Grabau (1900), Howell, Shimer, and Lord (1936), and B. F. Howell and G. S. Lord, unpublished.

72. Data for this column derived from G. F. Matthew, various papers, and Hayes and Howell (1937).

73. Data for this column derived from Matthew (1903).

74. Data for this column derived from Kindle (1938; 1942).

75. Data for this column derived from Schuchert and Dunbar (1934), Lochman (1938), Howell and Lochman (1938), Betz (1939), Johnson (1941), Howell (1943), and B. F. Howell, unpublished.

76. Data for this column derived from Howell (1925; 1926), Howell and Mason (1938), and B. F. Howell, unpublished.

77. Data for this column derived from Poulsen (1927).

78. Data for this column derived from Poulsen (1932).

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MANUSCRIPT RECEIVED BY THE SECRETARY OF THE SOCIETY, FEBRUARY 28, 1944.

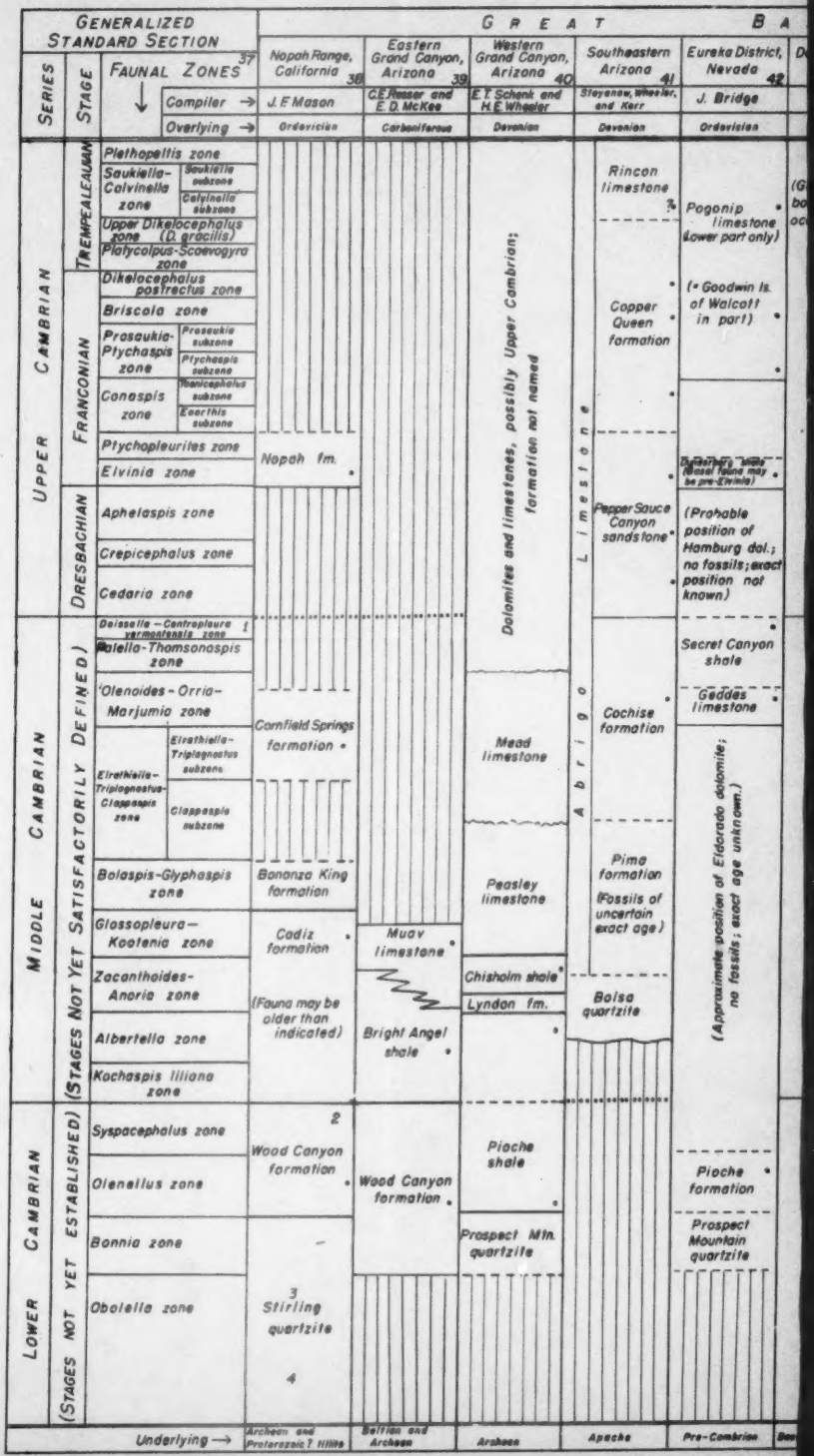
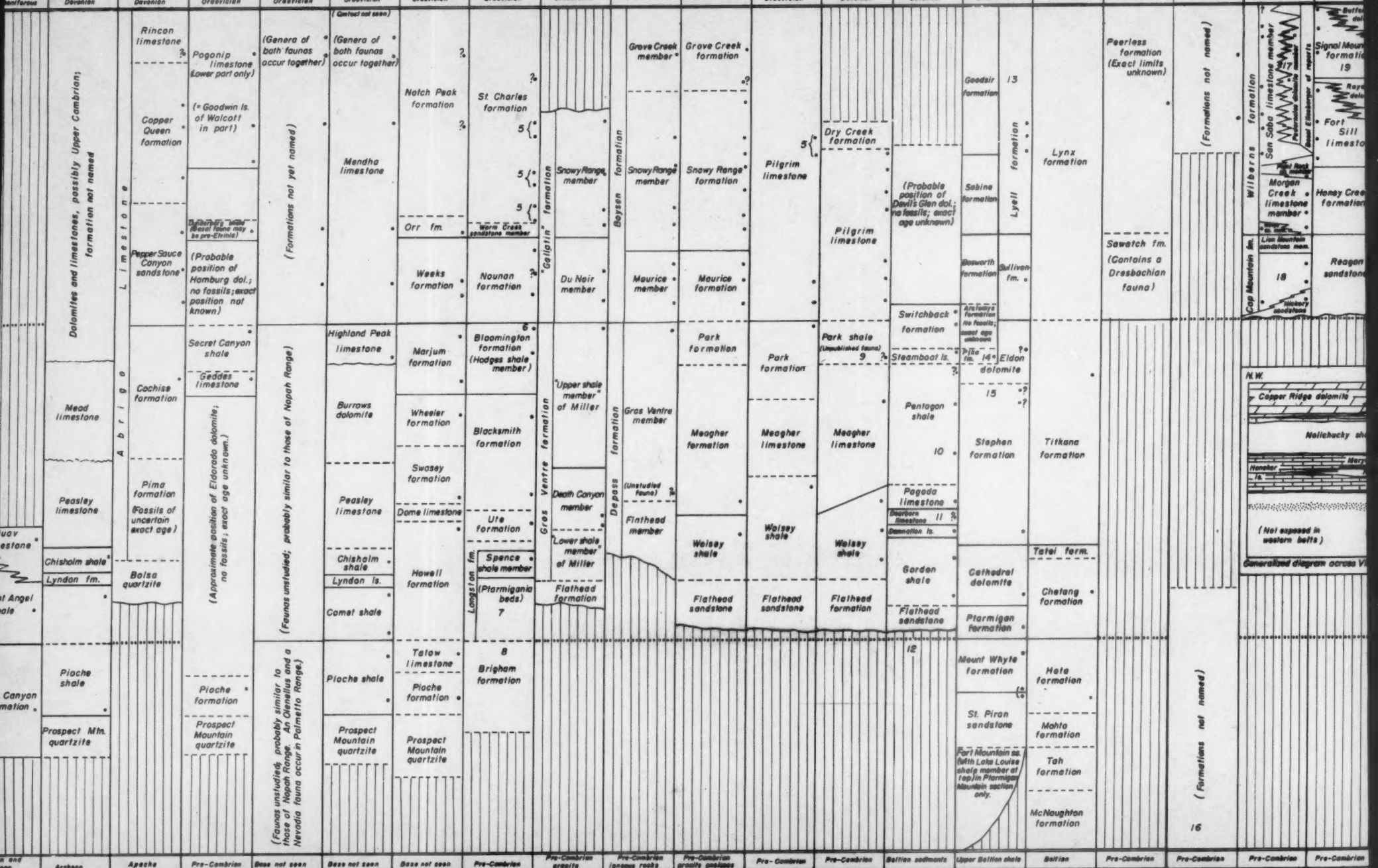

GENERALIZED STANDARD SECTION
GREAT BA
SERIES
STAGE
FAUNAL ZONES 37
Nopah Range, California 38
Eastern Grand Canyon, Arizona 39
Western Grand Canyon, Arizona 40
Southeastern Arizona 41
Eureka District, Nevada 42
Compiler →
J. F. Mason
C. E. Resser and E. D. McKee
E. T. Schenk and H. E. Wheeler
Stoyanow, Wheeler, and Kerr
J. Bridge
Overlying →
Ordovician
Carboniferous
Devonian
Devonian
Ordovician
UPPER CAMBRIAN
TREMPEALEAUAN
FRANCONIAN
DRESBACHIAN
MIDDLE CAMBRIAN
(STAGES NOT YET SATISFACTORILY DEFINED)
LOWER CAMBRIAN
(STAGES NOT YET ESTABLISHED)
Plethopeltis zone
Saukiella-Calvinella zone
Saukiella subzone
Calvinella subzone
Upper Dikelocephalus zone (D. gracilis)
Platycolpus-Scoevogyra zone
Dikelocephalus postrectus zone
Briscoia zone
Prosaukia-Ptychaspis zone
Prosaukia subzone
Ptychaspis subzone
Conaspis zone
Ivanicephalus subzone
Coorthis subzone
Ptychopleurites zone
Elvinia zone
Aphelaspis zone
Crepicephalus zone
Cedaria zone
Deiseella – Centropleura vermontensis zone
Ptarmigania-Thomsonaspis zone
'Olenoides-Orria-Marjumia zone
Elrathiella-Triplagnostus-Clappaspis zone
Elrathiella-Triplagnostus subzone
Clappaspis subzone
Bolaspis-Glyphaspis zone
Glossopleura-Kootenia zone
Zacanthoides-Anoria zone
Albertella zone
Kochaspis liliana zone
Syspacephalus zone
Olenellus zone
Bonnia zone
Obolella zone
Nopah fm.
Cornfield Springs formation
Bonanza King formation
Cadiz formation
(Fauna may be older than indicated)
2
Wood Canyon formation
3
Stirling quartzite
4
Muav limestone
Bright Angel shale
Wood Canyon formation
Dolomites and limestones, possibly Upper Cambrian; formation not named
Mead limestone
Peasley limestone
Chisholm shale
Lyndon fm.
Pioche shale
Prospect Mtn. quartzite
Abrigo Limestone
Rincon limestone
Copper Queen formation
Pepper Sauce Canyon sandstone
Cochise formation
Pima formation
(Fossils of uncertain exact age)
Bolsa quartzite
Pogonip limestone (Lower part only)
(= Goodwin ls. of Walcott in part)
(Probable position of Hamburg dol.; no fossils; exact position not known)
Secret Canyon shale
Geddes limestone
(Approximate position of Eldorado dolomite; no fossils; exact age unknown.)
Pioche formation
Prospect Mountain quartzite
Underlying →
Archean and Proterozoic? Hillis
Belt(ian) and Archean
Archean
Apache
Pre-Cambrian

CHART No. 1 - CORRELATION OF THE CAMBR

By the Cambrian Subcommittee, B. F. Howell *(Chairman)*, Josiah Bridge, Charles F. Deiss, Ira Edwards, Christina Loc


GREAT BASIN
ROCKY MOUNTAINS
ALASKA
MISS
Western Grand Canyon, Arizona 40
Southeastern Arizona 41
Eureka District, Nevada 42
Desert Range, Nevada 43
Highland Range, Nevada 44
House Range, Utah 45
Bear River Range, Utah 46
Wind River Range, Wyo. 47
Wind River Canyon, Wyo. 48
Grave Creek–Bear tooth Butte Region, Mont.-Wyo. 49
Big Snowy Mountains, Montana 50
Nixon Gulch–Three Forks Region, Mont. 51
Northwestern Montana 52
Flamigan and Castle Mountains, Alberta
Sawback Range, British Columbia 53
Robson Peak Region, B. C. 54
Front Range, Colorado 55
Eagle District, Yukon Valley 56
Central Mineral Region, Texas 57
Arbuckle Wichita Oklahoma
Rincon limestone
Copper Queen formation
Pepper Sauce Canyon sandstone
Cochise formation
Pima formation (Fossils of uncertain exact age)
Bolsa quartzite
Pioche shale
Prospect Mtn. quartzite
Dolomites and limestones, possibly Upper Cambrian; formation not named
Mead limestone
Peasley limestone
Chisholm shale
Lyndon fm.
Abrigo Limestone
Pogonip limestone (Lower part only)
(= Goodwin ls. of Walcott in part)
Secret Canyon shale
Geddes limestone
(Approximate position of Eldorado dolomite; no fossils; exact age unknown.)
Pioche formation
Prospect Mountain quartzite
(Genera of both faunas occur together)
(Formations not yet named)
(Faunas unstudied; probably similar to those of Nopah Range)
(Faunas unstudied; probably similar to those of Nopah Range. An Olenellus and a Nevadia fauna occur in Polmetto Range.)
(Contact not seen)
Notch Peak formation
Orr fm.
Weeks formation
Marjum formation
Wheeler formation
Swasey formation
Dome limestone
Howell formation
Tatow limestone
Pioche shale
Pioche formation
Prospect Mountain quartzite
Highland Peak limestone
Mendha limestone
Burrows dolomite
Peasley limestone
Chisholm shale
Lyndon ls.
Comet shale
St. Charles formation
Worm Creek sandstone member
Nounan formation
Bloomington formation (Hodges shale member)
Blacksmith formation
Ute formation
Langston fm.
Spence shale member
(Ptarmigania beds)
Brigham formation
Gallatin formation
Gros Ventre formation
Snowy Range member
Du Noir member
Upper shale member of Miller
Death Canyon member
Lower shale member of Miller
Flathead formation
Beyen formation
Depass formation
Grove Creek member
Snowy Range member
Maurice member
Gros Ventre member
Flathead member
Grove Creek formation
Snowy Range formation
Maurice formation
Park formation
Meagher formation
Wolsey shale
Flathead sandstone
Pilgrim limestone
Park formation
Meagher limestone
Wolsey shale
Flathead sandstone
Dry Creek formation
Pilgrim limestone
Park shale (Unpublished fauna)
Meagher limestone
Wolsey shale
Flathead formation
(Probable position of Devil's Glen dol.; no fossils; exact age unknown)
Switchback formation
Steamboat ls.
Pentagon shale
Pagoda limestone
Dearborn limestone
Damnation ls.
Garden shale
Flathead sandstone
Goodsir formation
Sabine formation
Bosworth formation
Archaeocyathid formation No fossils; exact age unknown
Ptarmigan fm.
Stephen formation
Cathedral dolomite
Ptarmigan formation
Mount Whyte formation
St. Piran sandstone
Fort Mountain ss. (with Lake Louise shale member at top in Ptarmigan Mountain section only.
Lyell formation
Sullivan fm.
Eldon dolomite
Lynx formation
Titkana formation
Tatei form.
Chetang formation
Hete formation
Mahto formation
Tah formation
McNaughton formation
Peerless formation (Exact limits unknown)
Sawatch fm. (Contains a Dresbachian fauna)
(Formations not named)
(Formations not named)
Wilberns formation
San Saba limestone member
Morgan Creek limestone member
Lion Mountain sandstone mem.
Cap Mountain lm.
Honeycut sandstone
Buffalo dol.
Signal Mountain formation
Fort Sill limestone
Honey Creek formation
Reagan sandstone
N.W.
Copper Ridge dolomite
Nolichucky sh.
Honaker
Eo.
(Not exposed in western belts)
Generalized diagram across Vi
Pre-Cambrian granite
Pre-Cambrian igneous rocks
Pre-Cambrian gravity gradients
Pre-Cambrian
Bottom sediments
Upper Bottom shale
Bottom
Archaean
Apache
Pre-Cambrian
Base not seen
Base not seen
Base not seen
Pre-Cambrian
Devonian
Devonian
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician
Devonian
Devonian
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician
Ordovician

N OF THE CAMBRIAN FORMATIONS OF NORTH AMERICA

F. Deiss, Ira Edwards, Christina Lochman, Gilbert O. Raasch, and Charles E. Resser, assisted by D. C. Duncan, J. F. Mason, and N. M. Denson.

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*.

ALASKA

(Formations not named)

MISSISSIPPI VALLEY

Central Mineral Region, Texas 57 — J. Bridge and G. Lochman — Ordovician
Wilberns formation
San Saba limestone member
Morgan Creek limestone member
Lion Mountain sandstone member
Cap Mountain fm.
18
17

Eagle District, Yukon Valley 55 — C. E. Resser — Ordovician

Arbuckle and Wichita Mtns., Oklahoma 58 — Bridge, Raasch, and Frederickson — Ordovician
Butterly dolomite
Signal Mountain formation
19
Royer dolomite
Fort Sill limestone
Honey Creek formation
Reagan sandstone

Black Hills, South Dak. 59 — C. Lochman — Ordovician
"Deadwood formation"

Ozark Region, Missouri 60 — C. Lochman and J. Bridge — Ordovician
Eminence dolomite
Potosi dolomite
Elvins group
Dee Run dolomite
Derby dolomite
Davis formation
Bonneterre dolomite
Lamotte ss.

Wisconsin–Minnesota 61 — G. O. Raasch and L. Edwards — Ordovician
Madison fm.
Prosser dolomite
Jordan mem.
Lodi mem.
St. Lawrence member 20
Bad Axe m.
Francania formation
Hudson member
Goodenough member
Ironton member
Dresbach fm.
Galesville m.
Eau Claire member
Mt. Simon ss.

APPALACHIAN REGION

N.E. Alabama, N.W. Georgia, and S.E. Tenn. 62 — C. E. Resser and J. Bridge — Ordovician
Copper Ridge dolomite
23
21
Bibb dol.
22
Ketona dol.
23
Longview limestone
Brierfield dolomite
25
Conasauga formation
Honaker limestone

Great Valley in N.E. Tenn. and S. Va. — west side 63 — east side 64 — C. E. Resser and J. Bridge — Ordovician
Copper Ridge dolomite
Conococheague limestone
Maynardsville limestone
Nolichucky shale
Maryville limestone
Rogersville shale
Rutledge limestone

Great Valley in southern Penn., Md., and north Va. 65 — C. E. Resser and J. Bridge — Ordovician
Conococheague limestone
Conasauga shale
Elbrook formation
Tomstown dolomite
Antietam quartzite

Central Pennsylvania 66 — C. E. Resser and B. F. Howell — Ordovician
Gatesburg formation
Mines member
Ore Hill member
Warrior formation
Pleasant Hill formation

S.E. Pennsylvania and Maryland 67 — Resser, Jones, and Stose — Ordovician
27
Frederick limestone
Ledger dol.
Kinzers shale
Vintage formation
Antietam sandstone
29

Northern New Jersey 68 — B. F. Howell — Ordovician
"Kittatinny formation"
30
Hardyston formation

Champlain Valley, N.Y. 69 — B. F. Howell and C. Lochman — Ordovician
Little Falls formation (including Hoyt member)
5
Theresa "formation"
5
Potsdam formation
(Pre-Cambrian granite)
Upper Hudson Valley
Schodack formation (Contains Elliptocephala zone)
Bomoseen formation
Nassau formation (Contains Oldhamia)

Western Vermont 70 — B. F. Howell and C. Lochman — Ordovician
5
Gorge formation
Pockwedge fm.
Hungerford fm.
Sass Brook ferm.
Shoals Corners fm.
Hill River ferm.
(Centropleura zone)
St Albans sh. 31
Rugg Brook formation
"Parker" formation
Mallett formation
Winooski formation
Monkton formation

NORTH ATLANTIC REGION

Eastern Massachusetts 71 — B. F. Howell — Carboniferous
Unnamed formation
32

Southeastern New Brunswick 72 — B. F. Howell — Ordovician
Narrows formation (Contains Paradoxides)
Black Shale
Brook formation (Olenus zone)
33
Agnostus Cove formation
Hastings Cove formation (Paradoxides davidis zone)
Porter Road fm. (Paradoxides hicksi zone)
Fossil Brook formation (Upper Paradoxides bennetti zone)
(Upper Paradoxides bennetti zone)
(Lower Paradoxides bennetti zone)
Waymouth and Hoppin formations (Contain Callavia zone)
Ratcliff Brook formation
Hanford Brook fm. (Protolenus zone)
Glen Falls fm.

Cape Breton, Nova Scotia 73 — B. F. Howell — Mississippian
Unnamed beds (Contain Paradoxides forchhammeri)
Unnamed beds (Contain brachiopods)

Gaspe Quebec 74 — C. H. Kindle — Ordovician
Murphy's Creek formation

Labrador and western Newfoundland 75 — Dobson, Dunbar, Lochman, Johnson, and Howell — Ordovician
Boulders in Cow Head cgl.
Petit Jardin formation
34
March Point formation
Unnamed form. in southwestern Newfoundland
Tregotyn Pond formation
Cloud Rapids formation (Unconformable on Partlow formation at Canada Bay)
Cambrian Brook fm.
Bradore formation
Cloud Mountain formation
35

Southeastern Newfoundland 76 — B. F. Howell — Ordovician
Series
Cove
Elliott
(Parabolina zone)
(Crusia zone)
(Olenus zone)
(Agnostus pisiformis zone)
Unnamed formation
(Paradoxides forchhammeri zone)
Kelligrew Brook formation (Paradoxides davidis zone)
Long Pond formation (Paradoxides hicksi zone)
(Upper Paradoxides bennetti zone)
(Lower Paradoxides bennetti zone)
Briqus formation (including Smith Point member)

ARCTIC REGION

Northwestern Greenland 77 — C. Poulsen — Ordovician
Pemmican River formation
Cape Wood formation
5
Cape Frederick VII formation
Cape Kent formation
Wulff River formation

Eastern Greenland 78 — C. Poulsen — Ordovician
Dolomite Point formation (exact horizon in middle Cambrian not known)
Hyolithes Creek formation
Ella Island formation
36
Bastion formation

(One or more formations older than the Murphy's Creek formation are present.)
Hawke Bay formation
Forteau formation
Devils Cove formation

FAUNAL ZONES OF NORTHWESTERN EUROPE

Peltura zone
Leptoplastus zone
Parabolina zone
Olenus zone
Agnostus pisiformis zone
Lejopyge laevigata zone
Paradoxides forchhammeri zone
Paradoxides davidis zone
Paradoxides hicksi zone
Paradoxides oelandicus zone
Protolenus zone
Olenellus zone
Callavia zone
Holmia zone
Obolella zone

N.W. — S.E.
Copper Ridge dolomite
Conococheague limestone
Nolichucky shale
Maryville ls.
Rutledge ls.
Conasauga shale
Rome formation
Shady dolomite
Erwin quartzite
Upper
Middle
Lower
(Not exposed in western belts)
Generalized diagram across Virginia–Tennessee state line (Not to scale)

(Formations not named)
16
Pre-Cambrian
Pre-Cambrian granite
Pre-Cambrian 24
Pre-Cambrian 25
Pre-Cambrian 26
Base not seen
Pre-Cambrian
Not exposed
Pre-Cambrian volcanics
Pre-Cambrian igneous & sedimentary rocks
Pre-Cambrian igneous & sedimentary rocks
Pre-Cambrian granite

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 55, PP. 1005–1046, 3 PLS., 1 FIG. AUGUST 1944

CORRELATION OF THE CRETACEOUS FORMATIONS OF THE GREATER ANTILLES, CENTRAL AMERICA, AND MEXICO

BY RALPH W. IMLAY

CONTENTS

Page
Introduction 1005
Annotations 1005
References to the Cretaceous of the Greater Antilles 1037
References to the Cretaceous of Central America and Mexico 1039

ILLUSTRATIONS

Figure Page
1. Index map of the Greater Antilles 1006

Plate Facing page
1. Lower Cretaceous fossil localities in Central America and Mexico 1012
2. Upper Cretaceous fossil localities in Central America and Mexico 1036
3. Correlation of the Cretaceous formations of the Greater Antilles, Central America, and Mexico (Chart 10a of series) 1046

INTRODUCTION

This is Number 10a of a series of correlation charts prepared under the auspices of the Committee on Stratigraphy of the National Research Council.[1] It was originally intended to publish this chart with others dealing with the western interior of the United States and Canada, but it is now realized that those regions will be represented by several charts as large as the present chart, and that some of the charts may not be completed for several years. It seems best, therefore, to publish each chart as soon as it is ready.

Rather complete lists of references are given for the convenience of future workers. References dealing with the Greater Antilles are listed separately from those dealing with the Central American-Mexican region, as the two regions seem to have very different geologic histories.

In the correlation chart age equivalencies are shown by horizontal lining, hiatuses by vertical lining, and lack of knowledge by oblique lining. The annotations are numbered to agree with numerals on the chart.

ANNOTATIONS

1. The Coahuila group was proposed originally (Imlay, 1940a, p. 124, 125) "to include all Lower Cretaceous strata older than the *Dufrenoya texana* zone which were deposited in the ancestral Gulf of Mexico, in the Mexican sea, and in closely connected waters." It is herein redefined as the Coahuila series and is subdivided into the

[1] Dunbar, C. O., *et al.* (1942) *Correlation charts prepared by the Committee on Stratigraphy of the National Research Council*, Geol. Soc. Am., Bull., vol. 53, p 429–434.

FIGURE 1.—*Index map of the Greater Antilles*

Nuevo León and Durango groups. This usage retains the Comanche series in the sense originally defined by R. T. Hill, emphasizes the magnitude of Coahuila time, and permits convenient grouping of the Mexican formations. The Nuevo León group belongs in the upper part of the Coahuila series, is limited basally by the lowest ranges of the ammonites *Pulchellia*, *Barremites*, and *Pseudohaploceras*, and corresponds to the Barremian and lower Aptian of the European sequence. The Durango group belongs in the lower part of the Coahuila series, is limited basally by the ammonites *Neocosmoceras*, *Spiticeras*, and *Himalayites*, and corresponds to the Berriasian, Valanginian, and Hauterivian of the European sequence.

1a. The oldest rocks exposed on the Virgin Islands and St. Croix consist of thick, highly deformed, locally metamorphosed, volcanic tuff and fragmental material, lava, and minor amounts of shale and limestone, which Kemp (1926, p. 49) called the Mount Eagle series, after Mount Eagle on St. Croix. Similar rocks at least 2000 meters thick on St. Thomas had previously been named by Cleve (1871, p. 4) the Blue Beach conglomerate and identified as Cretaceous. A rudistid fauna from St. Croix studied by T. W. Stanton (Vaughan, 1923, p. 305) contains species that occur in beds of Maestrichtian age at many places in the West Indies. Whether the rocks represent more than Maestrichtian time is not known.

2. Lower Cretaceous rocks probably do not outcrop in Puerto Rico. Hodge (1920, p. 192) said that two coral specimens from the upper part of his so-called "Barranquitas-Cayey series" of south-central Puerto Rico were identified with *Cladophyllia furcifera* Roemer from the Edwards limestone of Texas. However, Meyerhoff (1932, p. 343) found Upper Cretaceous fossils in the same "series" as well as in lower formations and was unable to locate Hodge's collections (personal communication) to recheck the identification of the corals. Below the lowest fossiliferous beds is a thick mass of coarse volcanic material (Meyerhoff, 1933, p. 52) which could be of Lower Cretaceous age but more likely is early Upper Cretaceous, considering the times of volcanism in the lands bordering the Gulf of Mexico.

Upper Cretaceous rocks crop out extensively in Puerto Rico and consist of volcanic and sedimentary materials ranging from 2 to 3 miles in thickness. They have yielded few fossils, and these have not been described. Three ammonites from near the top of the "Barranquitas-Cayey series" (Meyerhoff and Smith, 1931, p. 224, 225) have been identified by Reeside (in Meyerhoff, 1932, p. 342) as *Barroisiceras* aff. *B. haberfellneri* (van Hauer) and *Parapuzosia* aff. *P. corbarica* (Grossouvre) and assigned to the Coniacian stage of the middle Upper Cretaceous. The most abundant fossils, according to Meyerhoff (1932, p. 343) are rudistids which "have much in common with the genus *Barrettia*." The presence of *Barrettia* would indicate a late Late Cretaceous age for the beds in which it occurs, as MacGillavry (1937, p. 23–28) has presented strong evidence that the genus is of Maestrichtian age.

Many formational names have been proposed for the Upper Cretaceous rocks of Puerto Rico by various geologists working in different areas. It is impossible with present published information to correlate these sequences of formations with one another, or with the European stages, as the formations have, in general, not been traced from one area to another, and they contain few or poorly preserved fossils that have not been described. A preliminary analysis of the various proposed

FIGURE 1.—*Index map of the Greater Antilles*

lithologic divisions has been made by Meyerhoff and Smith (1931, p. 263–267), but obviously much more field and laboratory work needs to be done before a satisfactory correlation can be obtained. For the sake of completeness, a list of the formation names proposed by the various writers will be given below.

For the Fajardo district of northeastern Puerto Rico, several distinct but noncontiguous lithologic units were named by Berkey (1919, p. 18) as the La Muda limestone, the Trujillo Alto limestone, and the Fajardo shales. The stratigraphic position of these formations was later established by Meyerhoff and Smith (1931, p. 266–290), who introduced additional formation names but were unable to find fossils significant for age determination, except possibly some rudistids (Meyerhoff and Smith, 1931, p. 228) from La Muda limestone. The sequence from youngest to oldest proposed by them is as follows:

San Diego formation
Fajardo shales including Juan Ascencio member
Figuera formation
Trujillo Alto limestone
Luquillo formation
Rio conglomerate
La Muda limestone
Guaynabo formation
Hato Puerco tuffs
Guzman formation

The San Juan district, directly west of the Fajardo district, apparently has a similar sequence of formations, but the details have not been studied. Several distinct, noncontiguous lithologic divisions named by Berkey (1919, p. 18) and Semmes (1919, p. 62–72) include the Juan Ascencio chert, the Corozal limestone, and the Aguas Buenas limestone. Meyerhoff and Smith (1931, p. 222, 263, 264, 268, 269, 288) consider that the Juan Ascencio chert is a basal member of the Fajardo shales; that the Aguas Buenas limestones are apparently equivalent to the La Muda and Trujillo Alto limestones, and that the Corozal limestone may be identical with La Muda limestone.

The Humaco district in southeastern Puerto Rico was studied by Fettke (1924, p. 134–152), who found that the Cretaceous beds consist mainly of volcanic material. He applied the name Collores limestone to two units of limestone, which he believed were parts of one formation exposed on opposite limbs of a fold. However, Meyerhoff and Smith (1931, p. 264) consider that the two units are not identical and that they correspond to the La Muda and Trujillo Alto limestones of the Fajardo district.

The Coamo-Guayma district of south-central Puerto Rico was studied by Hodge (1920, p. 129–198), who divided the pre-Oligocene beds into many lithologic divisions and assigned them to the Lower and Upper Cretaceous and the Eocene. From youngest to oldest as listed by Hodge, they include the Rio Descalabrados series, Coamo Springs series, Rio Jueyes series, Guayama series, Sierra de Cayey series, Barranquitas-Cayey series, and Rio de la Plata series. Other workers (Meyerhoff and Smith, 1931, p. 219–229, 264, 265; Meyerhoff, 1932, p. 342, 343) have shown that these "series" contain Upper Cretaceous fossils; that no Lower Cretaceous or Eocene

fossils have yet been identified in Puerto Rico; that the stratigraphic succession proposed by Hodge does not take into account repetition of beds due to folding; and that his "series" are so broadly defined as to be of questionable utility.

The Ponce district in southwestern Puerto Rico was studied by Mitchell (1922, p. 246–256), who divided the Upper Cretaceous beds into the Rio Yauco shales, San Germán limestone, Peñueles shale, Ensenada shale, Coama limestone, and Guayabal limestone. He was not certain of the stratigraphic succession of these formations but found Upper Cretaceous rudistids and other fossils in many beds.

The Lares district in northwestern Puerto Rico was studied by Hubbard (1923, p. 25–29), who divided the Upper Cretaceous beds from youngest to oldest into the Rio Yauco series, Rio Blanco series, and Rio Culebrinas series. He considered the Rio Yauco series as probably equivalent to most of the Cretaceous sequence in the Ponce district. The utility of these terms can only be determined by detailed field work.

3. Very little information has been published concerning the Upper Cretaceous stratigraphy of the Island of Hispaniola. In the Dominican Republic the Upper Cretaceous rocks (Cooke, in Vaughan, *et al.* 1921, p. 53–56) consist of interbedded shale, sandstone, limestone, basalt flows, volcanic tuff, and other pyroclastic rocks that attain a great thickness and are locally considerably metamorphosed near intrusive masses. Fossils of positive Cretaceous age have been recorded only near Gurabo in the Province of Monte Christi. These were identified by T. W. Stanton as *Radiolites* sp. similar to *R. nicholasi* Whitfield and *Caprinula* (?) sp. *Radiolites nicholasi* Whitfield is placed by MacGillavry (1937, p. 41) in the genus *Bournonia*, of late Upper Cretaceous age, but the species has been found in Jamaica, St. Croix, and Perú associated with other fossils of Maestrichtian age.

The Cretaceous rocks of Haiti are similar lithologically to those of the Dominican Republic (Woodring and Brown, 1924, p. 93–98) and have furnished fossils that indicate the presence of most of the Upper Cretaceous and probably some late Lower Cretaceous. Rudistids from the arrondissements of Cap Haitien and Grand Rivière du Nord were identified by Stanton as *Radiolites nicholasi* Whitfield and *R.* sp. cf. *R. cancellatus* Whitfield and considered by him as indicative of high Upper Cretaceous. These species have been assigned to the genus *Bournonia* by MacGillavry, as indicated above, and have been recorded with other fossils of Maestrichtian age. Recently collections of ammonites were made by W. P. Woodring and L. S. Gardner from Rivière Corail, about 2 miles northwest of the junction with Grande Rivière de Jacmel in the southern part of Haiti. These have been identified by John B. Reeside, Jr. (unpublished manuscript) as *Baculites*, *Parapuzosia?*, *Pachydiscus*, and *Texanites*, and their age has been interpreted as late early Senonian (Santonian). Beds of argillite and metamorphosed limestone underlying large areas have been tentatively referred to the Lower Cretaceous (Woodring and Brown, 1924, p. 86–93). Still older schistose rocks have been referred questionably to the Paleozoic without any fossil evidence.

4. Upper Cretaceous beds in Jamaica are represented by the Blue Mountain series as restricted by Trechmann (1922, p. 422, 423). They consist of about 3000 feet of volcanic tuff, breccia, and flows interbedded with some fossiliferous shales, sandstone,

conglomerate, and rudistid-bearing limestone that are best developed in the western part of the Island (Trechmann, 1924). The conglomerates attain a thickness as great as 100 feet and consist of fragments of gneiss, schist, marble, limestone, and andesite (Trechmann, 1927, p. 27). The volcanic beds are characterized by black, brown, and red colors; the shales by black, gray, and red colors; and the limestones by gray, yellow, and pink colors. In the Kingston district (Matley, 1929, p. 450; 1940, p. 100; Trechmann, 1936, p. 256, 257) occur some red andesites and tuffs that Matley assigned definitely to the Cretaceous without presenting fossil evidence. They are overlain disconformably by the Wagwater group of conglomerate, sandstone, shale, gypsum, and limestone which Matley (1940, p. 100) says grades into the Richmond formation of Eocene age. The fact that the red andesites and tuffs have not furnished rudistid remains suggests that they represent only part of the Blue Mountain series. Matley (1940, p. 100) and Trechmann (1922, p. 424–429) agree that the top of the Cretaceous is marked by a stratigraphic break throughout Jamaica. The possible occurrence of beds older than Cretaceous is a subject of considerable dispute. Matley (1929; 1940, p. 100) has presented considerable evidence that the Upper Cretaceous beds are underlain by a thick, basal complex of schist, marble, gneiss, hornfels, lava, tuff, peridotite, diorite, and granodiorite, although admitting that the granodioritic intrusions may be of Cretaceous age. Trechmann (1936) has presented evidence that the base of the Blue Mountain series has not been found, that the metamorphic rocks have been produced by Cretaceous and Tertiary intrusions, and that the granodiorite intrusions are of early Tertiary age. The absence of granodiorite pebbles below the Wagwater group of probable Eocene age favors Trechmann's interpretation of the age of the granodiorite intrusions and metamorphism of Cretaceous beds near the intrusions but does not disprove the presence of a basement complex. Matley's evidence for the presence of such a basement seems well established considering (1) the obvious care and detail with which he has mapped the Kingston district of southeastern Jamaica, (2) the presence of gneiss, schist, and marble fragments in the conglomerates of the Blue Mountain series, and (3) the presence of similar strongly metamorphosed basement rocks in Hispaniola and Cuba. Possibly intrusions occurred both in pre- and post-Cretaceous times as in Cuba. In general, it seems likely that the Mesozoic history of Jamaica was similar to that of Hispaniola and Cuba.

The Cretaceous beds of Jamaica have been dated as late Late Cretaceous on the basis of ammonites and rudistids. An ammonite obtained by Trechmann (1936, p. 253) about "800 feet below a *Barrettia* limestone in the St. Ann's Great River Valley near the north coast" was identified by L. F. Spath as *Nowakites* aff. *N. paillettei* D'Orbigny and suggested as of late Coniacian or early Santonian age. Other ammonites from below the rudistid limetone near Port Antonio in northeastern Jamaica were identified by Spath (1925) as *Epigoniceras* sp. ind., *Parapachydiscus* aff. *P. stallauensis* (Imkeller) Spath, *P.* cf. *P. gollevillensis* (D'Orbigny), *Glyptoxoceras* cf. *G. rugatum* (Forbes), and *Baculites* sp. Spath considers that the species of *Parapachydiscus* indicates an upper Senonian (Campanian) age and that *Glyptoxoceras* and *Baculites*, which occur about 100 feet above the other ammonites, are probably of Campanian or later age. The rudistid beds include many species of

Barrettia, *Praebarrettia*, *Titanosarcolites*, *Biradiolites*, *Bournonia*, and other genera that are common in the high Upper Cretaceous beds of the Greater Antilles and Central America and are generally considered (MacGillavry, 1937, p. 23–28; Stephenson, 1938, p. 2) to be of Maestrichtian age. Still later Cretaceous beds must be represented by the thick conglomerates and shales that locally overlie the rudistid beds (Trechmann, 1927, p. 27).

5. The term Tuff formation has been applied (Rutten, 1936a, p. 4, 5, 7–10; Thiadens, 1937a, p. 5, 6, 11–40; Vermunt, 1937a, p. 5, 6, 15–22; MacGillavry, 1937, p. 4, 5, 8–20) to a thick formation consisting of spilites, tuffs, tuff-breccias, porphyries, diabases, green to black chert, gray limestone, and some shale. It does not contain sandstone or quartzite. The igneous rocks are dominantly green or greenish, and less commonly brownish or gray. The spilites and diabases generally show no trace of bedding, the porphyries occur as thin sills and as lava sheets, and the other rocks are distinctly bedded. Limestones are interbedded with the volcanic rocks, are most common in the lower part of the formation, and locally in the southern part of Santa Clara Province are so conspicuous that they have been named the Provincial limestone, after the town of Provincial (Thiadens, 1937a, p. 11, 12, 17, 18). The limestones are yellow to dark gray, mostly thin-bedded, locally oölitic, and generally contain many small fragments of volcanic material that may be unaltered or may be more or less calcified. The thickness of the Tuff formation in southern Santa Clara Province has been estimated by Thiadens (1937a, p. 5, 12) as about 8000 meters (26,240 feet), but this seems exorbitant.

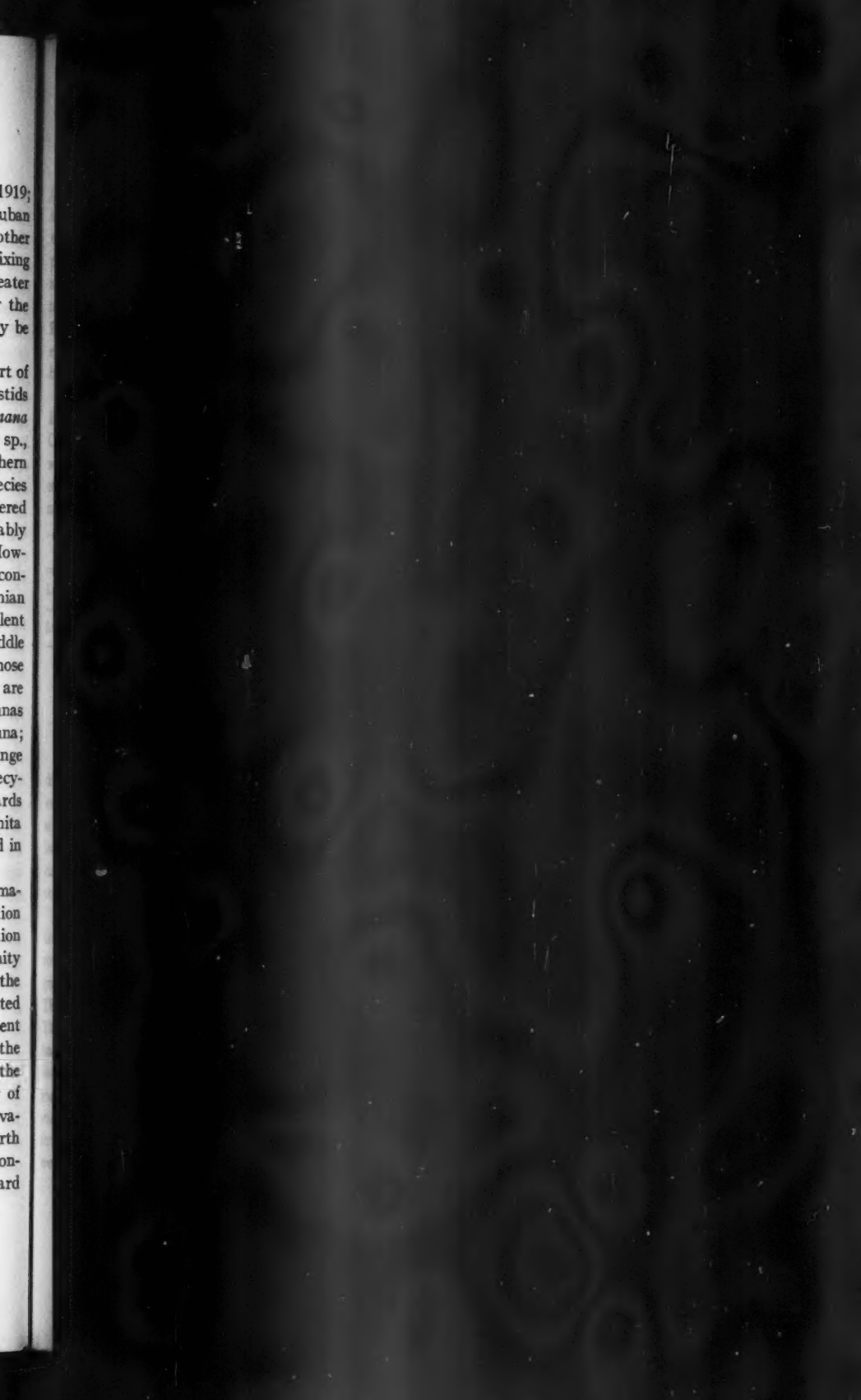
The Tuff formation rests with apparent conformity on the Viñales limestone, of late Jurassic age (Vermunt, 1936a, p. 5; MacGillavry, 1937, p. 7), but Dickerson (1937, p. 419) considers that the relationship is probably unconformable as shown by formational distribution. According to several Dutch geologists from the University of Utrecht, it is overlain with marked unconformity by the Habana formation of late Late Cretaceous age (Rutten, 1936a, p. 4, 5, 21, 24; Thiadens, 1937a, p. 5, 6, 40, 49; Vermunt, 1937a, p. 5, 6, 24, 32; MacGillavry, 1937, p. 5, 32) as shown by formational distribution, by local structural discordances involving faulting and strong folding, and by the occurrence within the Habana formation of conglomeratic material derived from all the underlying formations and from igneous rocks intruded into the Tuff series. It has been demonstrated that deposition of the Tuff formation was followed by intrusion of peridotite masses, then by gabbro dikes, and finally by quartz-diorite batholithic masses and dikes that caused considerable metamorphism of the Tuff formation. The intrusions were followed by folding which was gentle in northern Santa Clara Province and rather strong in western Pinar del Río, southern Santa Clara, and Camagüey Provinces. The folding was accompanied or followed by a period of erosion before deposition of the Habana formation.

The age of the Tuff formation is early Late Cretaceous, probably Cenomanian to Coniacian. A Turonian or Coniacian age is shown by some ammonites collected by Rutten (1936a, p. 7, 35, 36) from the upper part of the formation in the northern part of Santa Clara Province. These ammonites were identified provisionally by Jaworski as belonging to the genera *Austiniceras*, *Pachydiscus*, *Peroniceras*, *Barroisiceras*, and *Crioceras*. Most of the species were compared by him with species from Zum-

pango del Río, central Guerrero, Mexico, that were assigned by Burckhardt (1919; 1921; 1930, p. 236–238) to the Coniacian. However, both the Mexican and Cuban faunas contain some species which would normally indicate a Turonian age and other species which would indicate a Coniacian age. Thus, either there has been a mixing of species from different stratigraphic levels, or the range of the species are greater than elsewhere. At least, the Cuban ammonites must represent a level near the Turonian-Coniacian boundary, and the overlying tuffaceous beds might readily be of Coniacian age.

A Cenomanian to Turonian age for the Provincial limestones in the lower part of the Tuff formation of southern Santa Clara Province is indicated by the rudistids studied by Thiadens (1936a; 1936b; 1937a, p. 5, 12), who has identified *Coalcomana ramosa* (Boehm), *Caprinuloidea perfecta* Palmer, *Caprinuloidea* sp., *Sabinia* sp., and *?Tepeyacia corrugata* Palmer. Most of these species occur likewise in southern Mexico associated with many other rudistids, Nerineas, Actaeonellas, and a species of *Chondrodonta* similar to *C. munsoni* (Hill). This Mexican fauna was considered by Palmer (1928; Burckhardt, 1930, p. 205–209, 236) to be Cenomanian and probably also Turonian in age. Thiadens concurred with Palmer's age assignments. However, MacGillavry (1937, p. 5, 10–12), in a comprehensive study of rudistids, concluded that the rudistid faunas that Palmer assigned to the Cenomanian and Turonian are intimately related to rudistids in the Edwards limestone of Texas and equivalent beds in southern Mexico, whose age has been determined by ammonites to be middle Albian. Hence, MacGillavry concludes that all these rudistid faunas, including those in the Provincial limestones of Cuba, are of middle Albian age. His arguments are rather weak in the writer's opinion, because (1) the Cenomanian-Turonian faunas described by Palmer contain no species in common with the large Edwards fauna; (2) the genera common to these faunas, such as *Caprinuloidea* and *Eoradiolites*, range from the Albian into the early Late Cretaceous; and (3) species of the aberrant pelecypod *Chondrondonta* similar to *C. munsoni* (Hill) are not confined to the Edwards limestone, as MacGillavry intimates, but occur in rudistid limestones of the Washita group as high as the base of the Del Rio shale and may, therefore, be expected in rudistid limestones of Cenomanian age in Mexico.

6. The unconformity between the Tuff formation and the overlying Habana formation must be about Santonian in age, considering that the fossils in the Tuff formation indicate a Cenomanian to Coniacian age, and that the fossils in the Habana formation indlcate a Campanian and Maestrichtian age. Development of the unconformity during the Santonian corresponds closely with the time of development of one of the most pronounced disconformities in the Upper Cretaceous beds of the eastern United States. Stephenson (1936; Stephenson *et al.*, 1942, chart) has emphasized the extent and magnitude of the disconformity between the outcropping Austin chalk and the Taylor marl, or their equivalents from Texas to New Jersey, and has shown that the disconformity in most places is of Santonian age, but in some places is partly of Campanian age. The disconformity at any one locality may not be exactly equivalent to the disconformity at other localities owing to local movements of the earth or to the position of the locality with respect to the strand line, but the time of disconformity at all localities is near the Santonian-Campanian boundary. Roy T. Hazzard



LOWER CRETACEOUS FOSSIL

FOSSIL LOCALITIES IN CENTRAL AMERICA AND MEXICO

(personal communication) has stated that the disconformity of approximate Santonian time is one of the most widespread and conspicuous in the subsurface Upper Cretaceous beds of the Southern States. Reside (*in* Stephenson and Reeside, 1938, p. 1631) has indicated that fossils of definite upper Santonian and lower Campanian ages have not yet been found in the Great Plains area of the United States, although no physical evidence of a disconformity between the Niobrara formation and the Pierre shale has ever been recorded. For eastern Mexico, no faunal or physical evidence of a disconformity during Santonian time is known except in the area between the Sierra del Burro and the Río Grande.

7. The Habana formation of current usage was defined by Palmer (1934, p. 128–132) for about 7000 feet of Upper Cretaceous beds, particularly well exposed near the City of Habana and southward. He divided the formation into four members, to which he gave lithologic designations, apparently not recognizing the terms proposed earlier by Lewis (1932, p. 538, 539) or De Golyer (1918, p. 141, 142). The various names that have been proposed are as follows:

De Golyer, 1918	Lewis, 1932	Palmer, 1934	
Lucero formation	El Cana formation	Habana formation	Big Boulder shale
Luyano marls	Madruga chalk		Chalk
	Habana shale		Cone sandstone
			Lime Gravel

According to Lewis (1932, p. 538, 539), the Habana shale is "a series of thin-bedded dark green to light gray shales and sandy shales which are composed largely of volcanic ash" and is at least 2000 feet thick. The overlying Madruga chalk is "a series of white chalks and marls with occasional white shales and grits" and is at least 2000 feet thick. The overlying El Cano formation is "a series of thin-bedded clay shales, sandy shales, micaceous sandstones, sandstones, and conglomerates with occasional thin limestone" and is from 200 to 1000 feet thick.

According to Palmer (1934, p. 129–132) and Albear (1941, p. 558), the Lime Gravel member consists mainly of limestone cobbles and pebbles but includes some rounded boulders of andesite, rhyolite, and basalt. The Cone sandstone consists of gray, compact, calcareous sandstone that commonly has cone-shaped concretions. The Chalk member consists of hard to soft, white to grayish-white marl and chalk. The Big Boulder shale consists of soft, friable, brown shale composed of debris of basic igneous rock, alternating in places with hard limestone that weathers into large boulders. Palmer recognizes the Big Boulder shale as identical with the Lucero formation defined by De Golyer (1918, p. 142) and that it passes westward in the vicinity of Habana into the El Cano formation (Lewis, 1932, p. 539) consisting of interbedded sandstones and shales. He indicates that the lower members pass westward in the Habana area into gray and brown calcareous shales and marls.

The Dutch geologists from the University of Utrecht, who have published the most

recent accounts of the Cuban Cretaceous (Rutten, 1936a, p. 4–6, 20–42; Thiadens, 1937a, p. 6, 40–44; Vermunt, 1937a, p. 6, 22–27; MacGillavry, 1937, p. 5, 20–28), agree as to the usefulness of the Habana formation as defined by Palmer but consider that its local lithologic variations are not distinct or constant enough to warrant naming.

The Habana formation of Pinar del Río Province, as described by Vermunt (1937a, p. 6, 22–27, 36, 37) consists of two facies which he designates the "Mountain facies" and the "Eastern facies." The "Mountain facies," exposed in the mountainous regions, consists mainly of "dark-blue limestone breccias and conglomeratic sandstones" that rest disconformably on the Tuff formation of early Upper Cretaceous age as well as on the Viñales and San Cayetano formations of Jurassic age and which include rounded fragments of all these older rocks. The "Eastern facies," exposed north, south, and east of the mountainous regions, consists of

> "conglomerates, white to brown calcareous sandstones, marls, chalks, and white limestones—[that]—cannot be distinguished from the Upper Eocene and Oligocene strata when paleontological evidence is lacking. . . . The position of the beds of the Eastern facies seems to point to a younger age than that of the beds of the Mountain facies,"

although both facies carry the same Foraminifera of Maestrichtian age. Thicknesses of the formation are not mentioned.

The Habana formation of the northern part of Santa Clara Province, as described by Rutten (1936a, p. 4–6, 20–42), consists of a southern and a northern facies that grade into each other. The southern facies consists of tuffs, tuffaceous limestones, and limestones that locally contain many orbitoids and rudistids. The northern facies consists mainly of brecciated and conglomeratic limestones of which few layers bear orbitoids or rudistids. The nonfossiliferous, finely brecciated beds are difficult to distinguish from the Viñales limestone. Tuffaceous beds in the Habana formation are distinguished from similar beds in the underlying Tuff formation by their lighter color, fresher appearance, presence of much primary quartz, presence of clear, twinned plagioclase fragments, detrital dioritic material, intercalation with limestones that are lighter-colored than those in the Tuff formation, and by the presence of late Late Cretaceous Foraminifera. Both facies of the Habana formation rest unconformably on the Tuff formation of early Early Cretaceous age and on the Viñales limestone of Jurassic age, as shown by formational distribution and by the inclusion of pebbles derived from the older formations. Both facies are overlain disconformably by the Upper Eocene as shown by absence of faunas of latest Cretaceous and of early Eocene age and by the presence of a conglomerate at the base of the Eocene in the southwestern part of the province. Thicknesses of the formation in the northern part of Santa Clara Province have not been stated.

The Habana formation of the southern part of Santa Clara Province, as described by Thiadens (1937a, p. 6, 40–44), consists of limestones, marls, conglomeratic and tuffaceous limestones, and tuffs. It rests unconformably on the Tuff formation as well as on diorite masses intruded into the Tuff formation as shown by formational distribution and by its conglomeratic beds containing particles derived from these older formations. It is overlain unconformably by the Upper Eocene, although a structural discordance has been noted only in the eastern part of the province. It has furnished a large fauna of Maestrichtian age. A minimum thickness of 700 meters (2296 feet) is mentioned.

The Habana formation of Camagüey Province, as described by MacGillavry (1937, p. 5, 20–28, 32) consists mainly of volcanic tuffs but includes some limestone, tuffaceous limestone, sandy limestone, brecciated and conglomeratic limestone, marl, sandstone, and conglomerate. Breccias were noted only on the Sierra de Camajan. The term Loma Yucatan limestone was proposed by MacGillavry (1937, p. 20) for some rudistid-bearing limestone cropping out in two hills north of Camagüey City. This limestone differs from the remainder of the Habana formation of Camagüey Province by lacking detrital material, by lacking Maestrichtian Foraminifera, and by containing a rudistid fauna of probable Campanian age. The Habana formation rests disconformably on the Tuff formation and on the diorite masses intruded into the Tuff formation. It is overlain disconformably by Eocene rocks of which some are probably older than Upper Eocene. Thicknesses have not been mentioned.

The age of the Habana formation has been demonstrated to be Maestrichtian and probably also Campanian mainly on the basis of studies of rudistids and Foraminifera (Rutten, 1935, 1936b; D. B. K. Palmer, 1934; Thiadens, 1936a, 1936b; 1937b; Weisbord, 1934; Vermunt, 1937b, p. 263, 274; MacGillavry, 1937). The Loma Yucatan limestone cropping out north of Camagüey City (MacGillavry, 1937, p. 20, 115, 118) contains rudistids that are specifically unlike those in the remainder of the Habana formation but are identical with or similar to species from Curaçao, north of Venezuela (MacGillavry, 1932, p. 381–392), which are considered to be of Campanian age. Furthermore, thin sections of the limestones from Loma Yucatan in Cuba and from Curaçao did not have Foraminifera, such as orbitoids or *Camerina*, that characterize most of the Habana formation of Cuba. MacGillavry considers that the absence of these genera indicates an age older than Maestrichtian. Evidence for the Maestrichtian age of most of the Habana formation has been presented in detail by MacGillavry (1937, p. 23–28) and has been substantiated by Stephenson (1938, p. 2). It consists mainly of the occurrence of genera of orbitoid Foraminifera not known below the Maestrichtian, (2) of genera of rudistids of Maestrichtian or of latest Upper Cretaceous age, (3) of the occurrence of these rudistid genera in Jamaica above ammonites of Campanian age (Trechmann, 1927, p. 32, 63–65), and (4) of the occurrence of one of the genera *Titanosarcolites*, in the Kemp clay of Texas associated with *Sphenodiscus* (Stephenson, 1938, p. 2), a well-known Maestrichtian marker.

In summation, the Habana formation consists of interbedded limestone, marls, chalk, shale, sandstone, conglomerates, and tuffaceous beds that vary considerably lithologically within short distances. Tuffaceous material is lacking in Pinar del Río Province, is uncommon in northernmost Santa Clara Province, and constitutes the bulk of the formation in Camagüey Province. The formation rests unconformably on the Tuff series of early Upper Cretaceous age as shown by (1) formational distribution, (2) local structural discordances, and (3) its conglomeratic beds containing pebbles derived from the Tuff series. The Habana formation is overlain unconformably by Eocene limestone and marl, which locally has a basal conglomerate. It contains a large fauna, particularly rudistids and Foraminifera, which are mainly of Maestrichtian age, but some limestone beds near Camagüey City contain rudistids of probable Campanian age. Thicknesses ranging from 2300 to 7000 feet have been reported.

8. Upper Cretaceous beds exposed in the area between Lake Nicaragua and the Pacific Ocean have been correlated by means of Foraminifera with the Méndez formation of the Tampico area of Mexico and the Taylor and Navarro beds of Texas (Wegemann, 1931, p. 194; Schuchert, 1935, p. 607, 608).

9. Sapper (1937, p. 26, 27, 109) considered the Metapán beds of southern Guatemala, northwestern Salvador, and western and central Honduras equivalent to the Todos Santos beds of northern Guatemala and Chiapas and probably equivalent to the upper part of the Tegucigalpa beds of southern Honduras. This correlation is partially confirmed (Mullerried, 1939a, p. 47b, c; 1942a, p. 129; 1942b, p. 474, 475) by the presence of Early and Middle Jurassic plants in the lower part of the Metapán and Todos Santos beds. However, Neocomian fossils have been found only in the upper part of the Todos Santos beds of Chiapas (Mullerried, 1936, p. 36), which are apparently identical with the Tuxtla formation defined by Ver Wiebe (1925, p. 129, 131; Böse, 1905, p. 25, 26). Equivalent Neocomian beds cropping out near Chinameca and on Cerro Pelón in eastern Veracruz have been named the Chinameca limestone by Gibson (1936, p. 276, table opposite p. 288). The early Neocomian age of some of the Chinameca limestone is shown by the presence of *Olcostephanus* and *Neocomites*. The Barremian or Aptian age of the highest beds is indicated by the presence of *Pseudohaploceras*.

10. The Cobán limestone (also variously called Ixocy, Comitán, Sierra Madre, and White limestones) has furnished fossils of Albian and Turonian ages. The Trinity is represented by *Orbitolina texana* Roemer (Vaughan, 1932, p. 610, Mullerried, 1939a, p. 28, 41, 45–47) and the Fredericksburg by *Toucasia texana* (Roemer) and *T. patagiata* (White). The upper Albian and Cenomanian have not been identified. As evidence of the Turonian age of part of the limestone, Mullerried (1936, p. 38, 39) lists rudistids belonging to the genera *Distefanella*, *Sauvagesia*, *Radiolites*, and *Apricardia* and the ammonites *Acanthoceras* sp., *Lytoceras* (*Gaudryceras*) sp., and *Pachydiscus peramplus* var. *beyrensis* Choffat.

11. The Esquias formation of north-central Honduras has been considered of Early Cretaceous age solely on the basis of stratigraphic position, as the only listed fossils, *Lima* and *Inoceramus*, are not restricted to the Cretaceous.

12. The San Cristóbal formation was named by Ver Wiebe (1925, p. 129, 132) for 1300 to 3300 feet of sandstone, marl, limestone, and dolomite overlying the Tuxtla formation. As thus defined, its lower part includes the Cobán limestone of other writers. However, the San Cristóbal formation has furnished fossils representing various stages of the Upper Cretaceous and may usefully include the beds above the Cobán limestone as currently employed. The position of the boundary between these formations cannot be determined until more field work is done, but it would not be surprising if the boundary coincided with that between the Comanche and Gulf series of the southern United States.

The most common fossils in the San Cristóbal formation are rudistids including forms reported to range from upper Turonian to Maestrichtian (Mullerried, 1936, p. 37–39; 1942b, p. 476, 477; MacGillavry, 1934). Unfortunately, the age relationships of most of the rudistids with respect to the other faunal elements have not been determined. However, in southern Chiapas near Ocozocoantla the Turonian is

represented by the forms of *Acanthoceras* and *Pachydiscus* mentioned in the discussion of the Cobán limestone and the Coniacian probably by *Hauericeras* (Burckhardt and Mullerried, 1936, p. 321, 322). In the Verapaz district of north-central Guatemala the Santonian, or Campanian, is represented by an association of plants and of an *Inoceramus* closely related to *I. deformis* Meek, which is common in the Austin chalk of Texas (Stephenson and Berry, 1929). In the southern Petén area of northern Guatemala the high Upper Cretaceous is represented by *Pseudorbitoides israelskii* Vaughan and Cole (1932, p. 614–616, pl. 2), whose type specimens come from beds of early Taylor age in Louisiana. In Chiapas and northern Guatemala the Maestrichtian is probably indicated by the rudistid *Barrettia*, although Mullerried (1936, p. 38, 39) states that he found *Barrettia* stratigraphically below Turonian ammonites. MacGillavry (1937, p. 23–28) considers that such an apparent occurrence must be the result of some structural complication that was overlooked by Mullerried.

13. The lower Neocomian is represented (1) near Tlaxiaco by the ammonite *Subthurmannia* (Felix, 1891, p. 141), (2) at Parián by *Olcostephanus* and *Kilianella* (Barrera, 1933, p. 61–67), (3) at Monte Alban southwest of the city of Oaxaca by *Olcostephanus* (Burckhardt, 1930, p. 99). The lower Neocomian shale near the city of Oaxaca is overlain by compact, gray limestone similar to limestone of late Neocomian age near Tehuacán in southeastern Puebla.

14. An unconformable relationship of high Lower Cretaceous limestone with older beds occurs at many places in the States of Oaxaca, Veracruz, Puebla, Guerrero, and Michoacán. Near the city of Oaxaca the upper Neocomian limestone is overlain by a limestone breccia that basally contains fragments of sandstone, gneiss, and quartzite and overlaps onto gneiss on Monte Alban (Felix and Link, 1893, p. 12–36). Near Tomellin, Zimatlán, Miahuatlán, and San Pedro el Alto in Oaxaca occur high Lower Cretaceous limestone marked basally by a breccia that rests on gneiss (Burckhardt, 1930, p. 202–205). Between Huetamo and Pungarabato in Michoacán the upper Neocomian is overlain with angular unconformity by thick-bedded limestone and shale of probable late Early Cretaceous age (Hall, 1903). Similar relationships have been observed between Iguala and Teloloapán in northern Guerrero (Hall, 1903). In the Tehuacán-San Juan Raya area in southeastern Puebla, the San Juan Raya formation of Aptian age is reported (Aguilera, 1906, p. 21) to be much less folded than the overlying Cipiapa limestone, but this observation is disputed by Mullerried (1934, p. 73; 1942a, p. 135). In the Orizaba area of central Veracruz the lower Maltrata limestone of Aptian age is much less folded than the overlying beds of late Early Cretaceous age (Böse, 1899, p. 5–17; Burckhardt, 1930, p. 196). On available evidence the unconformity can be dated only as younger than upper Aptian and older than upper Albian. It probably represents only part of the lower or middle Albian and most likely corresponds with the end of Trinity or of Fredericksburg time when disconformities were developed in Texas.

15. Rudistid-bearing, thick-bedded limestone including some marly limestone and shale and marked basally in many places by a limestone breccia is widespread in southern Mexico at the top of the Lower Cretaceous sequence (Burckhardt, 1930, p. 202–205, 236; Hall, 1903; Mullerried, 1934, p. 73). Few fossils have been recorded,

8. Upper Cretaceous beds exposed in the area between Lake Nicaragua and the Pacific Ocean have been correlated by means of Foraminifera with the Méndez formation of the Tampico area of Mexico and the Taylor and Navarro beds of Texas (Wegemann, 1931, p. 194; Schuchert, 1935, p. 607, 608).

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represented by the forms of *Acanthoceras* and *Pachydiscus* mentioned in the discussion of the Cobán limestone and the Coniacian probably by *Hauericeras* (Burckhardt and Mullerried, 1936, p. 321, 322). In the Verapaz district of north-central Guatemala the Santonian, or Campanian, is represented by an association of plants and of an *Inoceramus* closely related to *I. deformis* Meek, which is common in the Austin chalk of Texas (Stephenson and Berry, 1929). In the southern Petén area of northern Guatemala the high Upper Cretaceous is represented by *Pseudorbitoides israelskii* Vaughan and Cole (1932, p. 614–616, pl. 2), whose type specimens come from beds of early Taylor age in Louisiana. In Chiapas and northern Guatemala the Maestrichtian is probably indicated by the rudistid *Barrettia*, although Mullerried (1936, p. 38, 39) states that he found *Barrettia* stratigraphically below Turonian ammonites. MacGillavry (1937, p. 23–28) considers that such an apparent occurrence must be the result of some structural complication that was overlooked by Mullerried.

13. The lower Neocomian is represented (1) near Tlaxiaco by the ammonite *Subthurmannia* (Felix, 1891, p. 141), (2) at Parián by *Olcostephanus* and *Kilianella* (Barrera, 1933, p. 61–67), (3) at Monte Alban southwest of the city of Oaxaca by *Olcostephanus* (Burckhardt, 1930, p. 99). The lower Neocomian shale near the city of Oaxaca is overlain by compact, gray limestone similar to limestone of late Neocomian age near Tehuacán in southeastern Puebla.

14. An unconformable relationship of high Lower Cretaceous limestone with older beds occurs at many places in the States of Oaxaca, Veracruz, Puebla, Guerrero, and Michoacán. Near the city of Oaxaca the upper Neocomian limestone is overlain by a limestone breccia that basally contains fragments of sandstone, gneiss, and quartzite and overlaps onto gneiss on Monte Alban (Felix and Link, 1893, p. 12–36). Near Tomellin, Zimatlán, Miahuatlán, and San Pedro el Alto in Oaxaca occur high Lower Cretaceous limestone marked basally by a breccia that rests on gneiss (Burckhardt, 1930, p. 202–205). Between Huetamo and Pungarabato in Michoacán the upper Neocomian is overlain with angular unconformity by thick-bedded limestone and shale of probable late Early Cretaceous age (Hall, 1903). Similar relationships have been observed between Iguala and Teloloapán in northern Guerrero (Hall, 1903). In the Tehuacán-San Juan Raya area in southeastern Puebla, the San Juan Raya formation of Aptian age is reported (Aguilera, 1906, p. 21) to be much less folded than the overlying Cipiapa limestone, but this observation is disputed by Mullerried (1934, p. 73; 1942a, p. 135). In the Orizaba area of central Veracruz the lower Maltrata limestone of Aptian age is much less folded than the overlying beds of late Early Cretaceous age (Böse, 1899, p. 5–17; Burckhardt, 1930, p. 196). On available evidence the unconformity can be dated only as younger than upper Aptian and older than upper Albian. It probably represents only part of the lower or middle Albian and most likely corresponds with the end of Trinity or of Fredericksburg time when disconformities were developed in Texas.

15. Rudistid-bearing, thick-bedded limestone including some marly limestone and shale and marked basally in many places by a limestone breccia is widespread in southern Mexico at the top of the Lower Cretaceous sequence (Burckhardt, 1930, p. 202–205, 236; Hall, 1903; Mullerried, 1934, p. 73). Few fossils have been recorded,

but Böse (1923a, p. 41) found an upper Albian ammonite, *Pervinquieria*, near Zimapán, Hidalgo, and a Cenomanian ammonite, *Mantelliceras*, near the city of Oaxaca (Böse, 1910, p. 8, 9). Near Atliaca in east-central Guerrero, Mullerried (1942, p. 36) found *Toucasia texana* (Roemer) and *T. patagiata* White of the middle Albian and *Orbitolina texana* Roemer of the lower Albian.

16. Thin-bedded, generally wavy-bedded limestone, including many nodules, lenses, and beds of black chert, is characteristic of the upper Albian and lower Cenomanian in many parts of Mexico, but in the deeper parts of the synclinal basins, as near Mazapil, Zacatecas, and San Pedro del Gallo, Durango, it includes the middle Albian. In the Orizaba area of west-central Veracruz it has been called the upper Maltrata limestone (Böse, 1899, p. 6–8; Burckhardt, 1930, p. 196–199). In the Sierras de Tamaulipas and San Carlos of Tamaulipas, it has been called the upper member of the Tamaulipas limestone (Muir, 1936, p. 25–32, 48; Böse and Cavins, 1927, p. 65; Kellum, 1937, p. 45; Imlay, 1937d, p. 218, 219). Throughout much of northern and central Mexico it has been called the Cuesta del Cura limestone (Imlay, 1936, p. 1125, 1126; 1937a, p. 613–615; 1938b, p. 1664, 1665, 1686, 1689–1692; Humphrey, 1941, p. 4). Böse and Cavins (1927, p. 23, 24, 64, 65, 86–90, Pl. 19) discussed it under the heading "upper Albian (or Vraconian)" and considered it a bathyal or deep-water facies, probably because of the presence of uncoiled ammonites. It constitutes one of the most uniform and widely distributed formations in all Mexico, attaining its thickest development in the central parts of the basins, and passing at their margins and over the platform areas into rudistid-bearing limestone of great thickness, or partly into thick rudistid limestone of middle Albian age and partly into extremely thin shale and thin-bedded limestone of late Albian-early Cenomanian age.

Fossils are rather uncommon in the Cuesta del Cura limestone. Middle Albian forms of *Oxytropidoceras* have been found only near Mazapil, Zacatecas, (Burckhardt, 1930, p. 126). Upper Albian forms of *Pervinquieria*, *Hysteroceras*, and many uncoiled ammonites have been found near Mazapil and Camacho in northern Zacatecas (Burckhardt, 1930, p. 168, 169; Böse, 1923a, p. 30–46, 59–63), near Noria de Angeles in southeastern Zacatecas (Böse, 1923a, p. 41), near Fresnillo in central Zacatecas (Burckhardt, 1930, p. 170), and in the Sierra de Catorce of northern San Luis Potosí (Böse, 1923a, p. 40, 167). Some of the uncoiled ammonites have been found near San Pedro del Gallo (Burckhardt, 1930, p. 168), along the southern and eastern margins of the Sierra de la Paila (Böse, 1906d, p. 2, 3; Burckhardt, 1930, p. 175, 176, 190, 191), and near Aramberri, Nuevo León (Burckhardt, 1930, p. 171). Similar appearing beds near the city of Colima in southwestern Mexico have furnished *Pervinquieria* (Böse, 1910, p. 653). Cenomanian forms of *Turrilites* and *Scaphites* have been recorded near Mazapil and Camacho in northern Zacatecas (Burckhardt, 1930, p. 126, 167, 169; Böse, 1923a, p. 31, 136–140, 161–164). Indirect evidence of the Cenomanian age of part of the Cuesta del Cura limestone is furnished by the presence of *Mantelliceras* in the highest part of the lower member of the Indidura formation of the Sierra de Santa Ana in southwestern Coahuila, which member occupies the same stratigraphic position as the Cuesta del Cura limestone a short distance to the south.

17. The only fossil recorded from the Neocomian beds of the Pungarabato-Huetamo area is *Nerinea titania* Felix (Hall, 1903, p. 333; Burckhardt, 1930, p. 161, 162) which occurs elsewhere in the upper Neocomian near San Antonia de Las Salinas in southeastern Puebla (Burckhardt, 1930, p. 160).

18. Shale, sandstone, and some limestone cropping out in the area between Iguala and Teloloapán in northern Guerrero (Hall, 1903) have been assigned to the low Lower Cretaceous (Burckhardt, 1930, p. 157, 158, 200), because they are more highly folded than the overlying thick-bedded limestone of the high Lower Cretaceous and because similar shale near Campo Morado, about 40 miles west-southwest of Iguala, contains an upper Aptian ammonite, *Dufrenoya*. Limestone containing the lower Albian ammonites *Uhligella mexicana* Burckhardt and *Acanthoplites* juv. cf. *A. bigoureti* (Seunes) is reported from San Gaspar Zumpahuacán in the southern part of the State of Mexico (Burckhardt, 1925, p. 12, 39; 1930, p. 137).

19. Gray, thick-bedded limestone bearing many rudistids of Cenomanian to Turonian age crops out extensively in west-central Oaxaca, northeastern Guerrero, Mexico, Morelos, Puebla, eastern Querétaro, western Hidalgo, central Veracruz, Colima, southern Jalisco, western Michoacán, and southwestern San Luis Potosí (Palmer, 1928; Mullerried, 1930; 1932b; Boehm, 1898; 1899; Douvillé, 1900; Burckhardt, 1930, p. 137, 206, 196–199, 235; Bárcena, 1875, p. 376, 377; 1877, p. 197; Böse, 1899, p. 8–11). The Cenomanian beds are richly fossiliferous, including many rudistids, Nerineas, corals, Foraminifera, and the aberrant pelecypod *Chondrodonta* that in Texas ranges from the Glen Rose limestone to the top of the Georgetown limestone. *Orbitolina* has been cited from the Escamela limestone of central Veracruz (Böse, 1899, p. 10; Burckhardt, 1930, p. 199; Palmer, 1928, p. 17) but has not been described or figured. If *Orbitolina* is actually present, it ranges much higher in Mexico than in the southern United States, or in northern South America, where it has not been found above the middle Albian. Among the many rudistids assigned to the Cenomanian some of the most typical are *Coalcomana ramosa* (G. Boehm), *Monopleura* (*Petalodontia*) *calamitiformis* Bárcena, *Caprinuloidea? felixi* (G. Boehm), and *C.? lenki* (G. Boehm). The Turonian beds are not very fossiliferous, but the most frequently cited rudistids include *Biradiolites lombricalis* D'Orbigny, *Apricardia chavesi* Palmer, *Tepeyacia corrugata* Palmer, and *Hippurites mexicanus* Bárcena. The Turonian age of these rudistids is based on the studies of Palmer and Mullerried cited above but is partly confirmed by a statement of MacGillavry (1937, p. 101, 105) that the Hippuritinae did not come into being until late Turonian time.

Near Ixmiquilpán in western Hidalgo the Turonian is represented by a shale and marl facies containing *Inoceramus labiatus* (Schlotheim) and *I. hercynicus* Petrascheck (Böse, 1923a, p. 45). This is the southernmost known occurrence of a facies that is widespread in Mexico, north of southern San Luis Potosí, and east of the Sierra Madre Oriental in Veracruz. In most parts of southern Mexico and Central America south of San Luis Potosí, the Turonian is represented by a rudistid-reef facies.

20. Near Zumpango del Río in east-central Guerrero a thick sequence of shale and limestone has yielded ammonites, gastropods, and *Inoceramus* representing the upper Turonian and lower Coniacian. Burckhardt (1919, p. 81–84, 93–132; 1921, Pls. 22–32; Böse, 1923a, p. 190–210, Pls. 13–17) considers that the Turonian is represented

by several species of *Scaphites* and the Coniacian by many species of *Peroniceras* and *Barroisiceras*. However, among the species listed as occurring together, some would normally indicate a late Turonian age, and others would indicate a Coniacian age. Near Mezquititlán, a few miles north of Zumpango del Río, have been found the lower Turonian ammonites *Hoplitoides*(?) and *Vascoceras* (Burckhardt and Mullerried, 1936, p. 321).

21. The middle Albian is represented near Ixmiquilpán, Hidalgo, by at least 1000 feet of thin- to thick-bedded limestone containing *Exogyra texana* Roemer, *Gryphaea tucumcarii* Marcou, *Toucasia texana* (Roemer), *T. patagiata* (White), *Orbitolina*, and *Coalcomana ramosa* (G. Boehm) (Mullerried, 1939b). The occurrence of *C. ramosa* with typical Fredericksburg fossils is significant, because elsewhere in Mexico it is associated with rudistids that have been considered of Cenomanian age and are very distinct from the middle Albian rudistids of the Edwards limestone of Texas. If Mullerried's identification is correct, *C. ramosa* must have a considerable stratigraphic range.

22. The Jurassic is overlain by about 985 feet of shale, marl, and limestone containing *Monopleura* and some corals that suggest a Neocomian age (Mullerried, 1934, p. 71, 79). Conformably above follows the Zapatitlán formation which ranges from 655 to 1310 feet in thickness and consists mainly of sandy to shaly marl but includes beds of limestone, sandstone, rock salt, and gypsum (Aguilera, 1906a; Mullerried, 1934, p. 65–74). At several levels it has furnished a large fauna of corals, Monopleuras, gastropods, echinoids, and basally the ammonites, *Holcodiscus*, *Pulchellia*, and *Olcostephanus*, whose association definitely proves the early Barremian age of the beds in which they occur (Felix, 1891, p. 142–172, Pls. 22–26; Douvillé, 1900; Mullerried, 1933b, p. 80–84; 1934, p. 55–80; Burckhardt, 1930, p. 160). The overlying San Juan Raya formation (Aguilera, 1906a, p. 15–21) ranges from 1640 to 2300 feet in thickness and consists mainly of marl, sandstone, and limestone but includes some conglomerate, salt, and gypsum. It has furnished a large fauna of echinoids, pelecypods, gastropods, ammonites, rudistids, and Foraminifera (Nyst and Galeotti, 1840; Cotteau, 1890; Mullerried, 1933b, p. 84–92; 1934, p. 55–63) of Aptian age. The occurrence of *Orbitolina* in this formation (Mullerried, 1934, p. 64) is of stratigraphic interest, but unfortunately the specimens have not been described or figured.

23. The lower Maltrata limestone is lithologically like the upper Maltrata limestone but is much more strongly folded (Burckhardt, 1930, p. 196). It contains *Dufrenoya justinae* (Hill) and *Parahoplites* sp. of late Aptian age (Böse, 1899, p. 8).

24. Ascertainment of the position of the Necoxtla shale within the Albian must await more field work.

25. Neocomian beds have been identified by Burckhardt (1930, p. 92, 93, 137) near Huayacocotla, Veracruz, and Huauchinango, Puebla, but without citing fossil evidence. South of Almanza, Veracruz, is a thick mass of Lower Cretaceous beds which have furnished *Olcostephanus* of probable middle Neocomian age, *Pseudohaploceras* of Barremian or Aptian age, and *Columbiceras* and *Acanthoplites* of late Aptian or early Albian age (Burckhardt, 1930, p. 93, 94). Near Zaragoza south of Zacapoaxtla in northern Puebla some marly limestone has furnished upper Aptian ammonites belonging to the genera *Procheloniceras*, *Cheloniceras*, *Puzosia*, and *Aconeceras* (Burckhardt and Mullerried, 1936, p. 317).

26. The term Tamaulipas limestone has been applied to a sequence of dense, medium- to thick-bedded limestone of late Comanche age as typically exposed in the Sierra de Tamaulipas. The term has also been applied to similar limestone in the Sierra de San Carlos of Tamaulipas, in the northern oil fields near Tampico, and in the Sierra Madre Oriental of Veracruz (Böse and Cavins, 1927, p. 60–67; Muir, 1936, p. 15, 21–36, Fig. 12; Kellum, 1937, p. 38–53; Imlay, 1937d, p. 217–221). In the Sierra de Tamaulipas the Tamaulipas limestone comprises three lithologic units. The lowest unit consists of about 50 feet of black, thin-bedded limestone, contains lower Albian or upper Aptian ammonites, and was named the Otates beds by Muir (1936, p. 28). The middle unit consists of 305 to 350 feet of light-gray, mostly thick-bedded limestone, and contains middle Albian fossils. The highest unit consists of 138–420 feet of wavy-bedded, thin-bedded limestone, including lenses of black chert, and on the basis of stratigraphic position is assigned to the upper Albian and lower Cenomanian. It is lithologically similar to and occupies the same stratigraphic position as the Cuesta del Cura limestone throughout much of north-central Mexico. In the northern oil fields the upper part of the sequence is similar to that in the Sierra de Tamaulipas, but below the Otates beds is 950 to 1050 feet of white to light-gray, hard, chalky limestone, then 75 feet of white to yellowish-gray, coarsely crystalline limestone containing ammonites of Berriasian and Valanginian age, and at the base is 5 feet of glauconitic sandstone that rests on Upper Jurassic limestone. In the Sierra de San Carlos the upper part of the sequence is very similar to that in the Sierra de Tamaulipas, but the Otates beds contain fossils of both early Albian and late Aptian ages and are underlain by a great thickness of thick-bedded limestone which has furnished Berriasian ammonites. The term Tamaulipas limestone has been applied by petroleum geologists to all these beds, although there are clearly five distinct lithologic units that correspond closely lithologically and stratigraphically with formations in north-central Mexico. For example, in comparison with the section in the middle part of the Sierra de Parras of southern Coahuila the lowermost unit containing lower Neocomian fossils is similar to the Taraises formation; the overlying unit of hard, chalky limestone corresponds to the Cupido formation and the lower part of the La Peña formation; the overlying Otates beds are similar lithologically and stratigraphically to the upper member of the La Peña formation; the overlying thick-bedded limestone occupies the same stratigraphic position as the Aurora limestone, although belonging to a different facies; and the highest unit of the Tamaulipas limestone is easily identified with the Cuesta del Cura limestone. Mullerried (1936, p. 31), at Burckhardt's suggestion, divided the Tamaulipas limestone into upper and lower Tamaulipas limestone and placed the boundary between these divisions at the base of the Otates beds, which he considered the base of the Albian. However, the Otates beds are now known to be in part of late Aptian age, so the boundary corresponds with the base of the upper Aptian, or of the Trinity group of Texas.

Lower Cretaceous fossils have been recorded from three wells in the northern oil fields. In the Corona Petroleum Company's Chocoy well no. 2, about 33 miles northwest of Tampico, the Berriasian is indicated by *Berriasella*, *Neocosmoceras*, *Spiticeras*, and *Hemispiticeras*, and the Valanginian by *Thurmannites* and *Valanginites*. In the Mexican Gulf Oil Company's Altamira well no. 11, about 5 miles south-

west of the Chocoy well no. 2, the Valanginian, or lower Hauterivian, is indicated by *Acanthodiscus* and *Oosterella* (Burckhardt, 1930, p. 95). In the Llano de Bustos well no. 1, about 15½ miles south of Tampico, the Berriasian and Valanginian are indicated by *Bochianites, Platylenticeras, Berriasella, Neocomites, Olcostephanus, Valanginites,* and *Himalayites* (Burckhardt and Mullerried, 1936, p. 317). In the same well the lower Albian is probably indicated by *Acanthoplites bigoureti* (Seunes).

Only late Early Cretaceous fossils have been found in the Tamaulipas limestone of the Sierra de Tamaulipas. The Otates beds in Cañón de Otates have furnished *Puzosia* and *Hypacanthoplites* (Muir, 1936, p. 27). In Cañón de los Perales they have furnished *Puzosia* cf. *P. kiliani* Fallot, *Columbiceras, Uhligella,* and *Inoceramus* cf. *I. anglicus* Woods (Böse and Cavins, 1927, p. 64). These fossils might indicate either a late Aptian or an early Albian age. From a thick-bedded limestone above the Otates beds in Cañón de los Perales was obtained *Lyelliceras prosocurvatum* (Gerhardt) (1897, p. 168, Pl. 4, figs. 8a, b; Riedel, 1938, p. 53, Pl. 9, figs. 3, 4), which genus, according to Spath (1931, p. 315), is restricted in Europe to the upper part of the lower Albian and the lower part of the middle Albian. Near El Pinto at the eastern end of Cañón de la Borrega, the thick-bedded limestone above the Otates beds have furnished *Oxytropidoceras acutocarinatum* (Shumard) (Muir, 1936, p. 27), a definite middle Albian marker. From an undesignated locality in the Tamaulipas limestone have been recorded *Alectryonia carinata* Lamarck, *Inoceramus* cf. *I. concentricus* Parkinson, *I. comancheanus* Cragin, and *Idiohamites comanchensis* (Adkins and Winton) (Muir, 1936, p. 32). The last two species are found in Texas in the Duck Creek formation of earliest late Albian age.

In the Sierra de San Carlos of Tamaulipas the Berriasian is represented by *Neocosmoceras* (Burckhardt, 1930, p. 266; Kellum, 1937, p. 39, 45, 84, 85, Pl. 9, fig. 11); the upper Aptian by *Pseudohaploceras, Beudanticeras,* and *Acanthoplites* cf. *A. multispinatus* (Anthula) (Kellum, 1937, p. 45, 46, 74–79); the lower Albian by species of *Puzosia, Uhligella, Hypacanthoplites, Acanthoplites, Parahoplites,* and *Inoceramus* that have been identified, or compared with European species (Böse and Cavins, 1927, p. 60); and the middle Albian by *Beudanticeras, Latidorsella, Puzosia, Uhligella, Engonoceras, Oxytropidoceras, Inoceramus* aff. *I. concentricus* Parkinson, and *I. subsulcatiformis* Böse (Kellum, 1937, p. 45–47). Significantly some middle Albian fossils were obtained only 20 feet below the base of the upper member of the Tamaulipas limestone, which must therefore represent the upper Albian.

27. The most widespread unconformity in the Cretaceous of Mexico appears to coincide with the unconformity between the Comanche and Gulf series in the southern United States. Wherever fossils have been found in the highest beds of the El Abra limestone, Cuesta del Cura limestone, or equivalent beds, they indicate an early Cenomanian age. The next overlying formation, such as Agua Nueva limestone, Indidura formation, or equivalent beds, are mainly of Turonian age but locally have furnished late Cenomanian ammonites in their basal beds. However, a definite unconformity can be demonstrated at only a few places such as (1) 18 kilometers south-southwest of Tamazunchale, San Luis Potosí (Muir, 1936, p. 32, 53), (2) west of Ciudad Victoria and Huizachal in southwestern Tamaulipas (Muir, 1936, p. 48; Heim, 1940, p. 322, Fig. 3), (3) in the area between the Sierra del Burro and the Río

Grande (Burckhardt, 1930, p. 190), (4) in the lower part of the valley of the Río Conchos in eastern Chihuahua (Burckhardt, 1930, p. 187), and (5) in the Sierra de Santa Eulalia in central Chihuahua (Vivar, 1912, p. 23). In most places no evidence of an unconformity has been found, but the slight thickness of beds that can be assigned to the Cenomanian suggests slow deposition or even nondeposition of sediment for a considerable time. Thus, in eastern Mexico the basal few feet of the Agua Nueva formation that contains fish scales and bones (Muir, 1936, p. 46, 48) may represent the middle and upper Cenomanian. Likewise, over the site of the Coahuila Peninsula the deposits of Cenomanian age are extremely thin. For instance, in the Sierra de Santa Ana in southwestern Coahuila the entire upper Albian and lower Cenomanian are represented by 65 feet of shale and platy limestone, and the remainder of the Cenomanian and the lower and middle Turonian are represented by 60 feet of limestone and shale (Kelly, 1936, p. 1028, 1029; Jones, 1938, p. 86–93). Evidently at the end of Comanche time most of northern Mexico was elevated sufficiently that parts of the sea floor were exposed to erosion and others were raised to or above the base level of deposition.

28. The Turonian age of most of the Agua Nueva formation is shown by the presence of *Inoceramus labiatus* (Schlotheim) and *I. hercynicus* Petrascheck (Burckhardt, 1930, p. 221; Muir, 1936, p. 45, 46). However, a Cenomanian ammonite, *Mantelliceras* aff. *M. couloni* (D'Orbigny), was found by Adkins (Muir, 1936, p. 53) 10 feet above the base of the formation in a road cut 18 kilometers southwest of Tamazunchale. Muir (1936, p. 53) considers that "at least the basal 15 feet of the Agua Nueva in the Sierra Tamaulipas and in the subsurface in the Pánuco area should be referred to the Cenomanian and not to the Turonian."

29. In the southern oil fields near Tuxpan, Veracruz, the San Felipe formation locally overlaps the Agua Nueva formation onto the El Abra limestone and is marked basally by a conglomerate derived from the El Abra limestone (Muir, 1936, p. 67). In the front ranges west of Tampico the San Felipe formation at many places grades downward into the Agua Nueva formation, but at other places, as along the eastern margins of the Sierras del Abra, Cucharas, and Colmena, it overlaps onto the El Abra limestone (Muir, 1936, p. 61, 62; Heim, 1940, p. 328, 329, Pl. 16). Its thickness ranges from about 1300 feet to the vanishing point depending on the overlap relationships of itself and of the overlying Méndez shale (Kellum, 1930, p. 88). These relationships show that the front ranges west of Tampico emerged from the sea as islands at the end of Agua Nueva (Turonian) time, underwent erosion, involving partial removal of the Agua Nueva and El Abra formations, and then gradually sank beneath the sea during San Felipe (Coniacian to Santonian) time.

30. The age of the San Felipe formation is based partly on its superposition on the Agua Nueva formation containing the characteristic Turonian species *Inoceramus labiatus* (Schlotheim) and partly on fossils that furnish a correlation with the Austin chalk of Texas which is considered of Coniacian and Santonian age (Stephenson and Reeside, 1938, p. 1631, 1638). Fossils collected by Stephenson (1922; Burckhardt, 1930, p. 229) from the upper part of the San Felipe formation on the Chocoy and Manuel haciendas northwest of Tampico include *Balanocrinus mexicanus* Springer, *Inoceramus* of large size, *Ostrea plumosa* Morton, *O. congesta* Conrad(?), and *Sauva-*

gesia degolyeri Stanton(?). According to Stephenson, the large Inocerami and *Ostrea congesta* Conrad(?) furnish a correlation with the Austin chalk, and the presence of *Ostrea plumosa* Morton indicates an age not older than the upper part of the Austin chalk. Further correlation with the Austin chalk is shown by the presence of *Inoceramus* cf. *I. deformis* Meek and *Ostrea congesta* Conrad(?) in the San Felipe formation of the Sierra de Tamaulipas (Stephenson, 1922, p. 2, 3) and by a rudistid resembling *Sauvagesia degolyeri* Stanton in the Austin chalk of Travis County, Texas (Adkins, 1930, p. 99).

31. Correlation of the Méndez shale with the Taylor and Navarro of Texas is based mainly on studies of the rudistids (Adkins, 1930; Stephenson, 1922; 1933), Foraminifera (Cushman, 1925; 1926a; 1926b; 1927a; 1927b; White, 1928; 1929), and on regional stratigraphic relationships (Muir, 1936, p. 71–74, 76). Stephenson (1941, p. 29, 35, 36) considers that the upper part of the Méndez shale that contains *Tampsia bishopi* Stephenson is a Navarro equivalent and of Maestrichtian age. It is not known whether the Méndez shale includes the latest Maestrichtian.

32. The contact between the Méndez shale and the Tamesí (Velasco) formation in the northern oil fields is marked by a bed of volcanic ash, by bentonite (Muir, 1936, p. 76, 90), or in places by a limestone conglomerate (Morgan, 1931). Near El Mulato north of the Sierra de San Carlos of Tamaulipas, the base of the Tamesí formation is marked by 4 to 15 feet of sandstone containing limestone conglomerate and locally shale fragments derived from the underlying Méndez shale (Muir, 1936, p. 85). A disconformity between the formations is strongly indicated by the microfossils, according to Barker (1936, p. 442, 443) and Thalmann (1935).

33. The age of the Tamesí (Velasco) formation has been discussed in detail by Muir (1936, p. 90–92) who considers that the formation is of late Cretaceous age and probably represents the Danian stage. The evidence given for a Cretaceous age consists of the presence of the Foraminifera *Globotruncana* and striate Gümbelinae which Muir says are world-wide in the Upper Cretaceous but unknown in the Tertiary. His assignment of the formation to the Danian, rather than the late Maestrichtian, is based mainly on reports of paleontologists that the microfauna is younger than the Navarro group of Texas and on the presence of Maestrichtian fossils in the upper part of the Méndez shale. His conclusions are accepted by Keller (1937, p. 837, 838) but rejected by Thalmann (1935) and Barker (1936, p. 442, 443), who consider the Tamesí formation probably of Paleocene age. Their conclusion is substantiated by the discovery of a Velasco fauna at the base of the Tertiary in Florida and Mississippi.

34. The term El Abra limestone has been applied to miliolid- and rudistid-bearing beds of late Early Cretaceous age in the southern oil fields near Tuxpan, Veracruz (Muir, 1936, p. 40–43), and in the front ranges of the Sierra Madre Oriental from the vicinity of Gomez Farias southward to Tamazunchale (Kellum, 1930; Muir, 1936, p. 24, 36–40; Imlay, 1937b, p. 556; 1939a, p. 15; Heim, 1940, p. 321, 324–326, Pl. 16). The El Abra limestone comprises two main facies. The upper 200 meters of the limestone is characterized by an abundance of miliolids and is called the El Abra facies. The remainder of the limestone is characterized by many rudistids and is called the Taninúl facies. Both facies contain interbeds of the other, as well as units

of dense limestone resembling the Tamaulipas limestone. Heim (1940, p. 321, 324–326, Pl. 16) shows that in the mountains west of Victoria, Tamaulipas, and south of Xilitla, San Luis Potosí, the miliolid facies overlies dense, chert-bearing limestone of the Tamaulipas facies. Because of these interfingering and intergrading relationships, Heim proposed the term Tamabra formation to include the approximately contemporaneous facies below the Agua Nueva formation.

The age of the El Abra limestone ranges from early Cenomanian to late Albian. Evidence for an early Cenomanian age of the highest part of the formation consists of the occurrence of *Pecten* (*Neithea*) *roemeri* Hill in limestone underlying the Agua Nueva formation at (1) Riachuelos, about 20 kilometers west of Xicotencatl in San Luis Potosí, (2) near Rascón west of Micos in San Luis Potosí, and (3) from two wells in the southern oil fields of Veracruz (Muir, 1936, p. 39, 41). Evidence for the middle Albian age of the Taninúl rudistid member was obtained by Adkins (1930, p. 82) at several localities in the Sierra del Abra, where he obtained such significant species as *Toucasia texana* (Roemer), *Eoradiolites* cf. *E. davidsoni* (Hill), and *E.* cf. *E. quadratus* Adkins. Other evidence of middle or early Albian age consists of the presence of *Orbitolina texana* (Roemer) (1) in a core taken 5114 feet below the top of the formation in the Penn Mex-Jardín no. 35 well located about 14 miles west-southwest of Tuxpan (Muir, 1936, p. 40, 41), and (2) in a section near Miquihuana in southwestern Tamaulipas (Imlay, 1937b, p. 556).

35. The Tamasopo limestone consists mainly of thick-bedded, dense, brittle, light-buff, rudistid-bearing limestone but contains some shale layers, particularly near its top, and has an estimated thickness of 3,300 to 6,560 feet. It grades eastward into the Agua Nueva and San Felipe formations near Rascón and Llanito in eastern San Luis Potosí. It grades northward into the San Felipe formation near El Capulín in southwestern Tamaulipas. Its western and southern extensions are not known. It is overlain by the Méndez shale near Canoas in San Luis Potosí and near Tula in southwestern Tamaulipas (Böse, 1906a; 1906b; Böse and Cavins, 1927, p. 77, 78, 97; Burckhardt, 1930, p. 231–233; Muir, 1936, p. 20, 60, 67, 73; Heim, 1940, p. 331–333). These regional stratigraphic relationships indicate that the Tamasopo limestone is equivalent to the upper part of the Agua Nueva formation and the entire San Felipe formation. Muir's (1936, p. 20, 73) suggestion that the upper part of the Tamasopo limestone is equivalent to the lower part of the Méndez shale of the Tampico area seems unlikely, because of the occurrence of a conglomerate at the base of the Méndez shale directly above the Tamasopo limestone near Canoas (Heim, 1940, p. 332).

The fauna of the Tamasopo limestone has not been studied. *Sauvagesia* has been recorded in its lower and middle parts, and *Coralliochama* and *Biradiolites* in its upper part (Böse and Cavins, 1927, p. 77). Northwest of Llanito in eastern San Luis Potosí the uppermost beds of the formation have furnished *Acteonella burckhardti* Böse, which characterizes beds of Coniacian age near Zumpango del Río, Guerrero (Muir, 1936, p. 61), but the range of the species is not known. The presence of *Coralliochama* is not evidence of a Campanian age for the upper part of the formation, as the type of the genus occurs in beds of Turonian age (Anderson and Hanna, 1935, p. 7, 14, 18, 31).

36. The Cárdenas formation has been studied, and its thickness of many thousands

of feet has been confirmed by several geologists (Böse, 1906a; 1906b; Heim, 1940, p. 332; Mullerried, 1941, p. 29), but no details of the section have been published. It extends northward as far as Tula in southwestern Tamaulipas (Heim, 1940, p. 332) and may be equivalent to the sandy shale at the top of the Méndez shale near Guerrero in easternmost San Luis Potosí (Muir, 1936, p. 74, 75). Its large fauna includes such diagnostic Navarro markers as *Exogyra cancellata* Stephenson, *E. costata* Say, and *Sphenodiscus* cf. *S. lenticularis* Owen (Stephenson, 1933; Muir, 1936, p. 72, 73; Burckhardt and Mullerried, 1936, p. 321).

37. Limestones near Charcas in west-central San Luis Potosí have furnished the Valanginian or early Hauterivian ammonites *Distoloceras* and *Neocomites* (Fernández, 1922, p. 492, Figs. 10–12; Burckhardt, 1930, p. 136). Chert-bearing limestone on Cerro de San Pedro, about 12 miles northeast of the city of San Luis Potosí, have furnished the ammonites *Astieridiscus* and *Olcostephanus*, whose association is evidence of a Hauterivian age (Finlay, 1903, p. 60; Fernández, 1922, p. 489, Fig. 3; Burckhardt, 1930, p. 137).

38. From the mountains near Barbosa, about 20 miles east of the city of San Luis Potosí, have been obtained *Hippurites mexicanus* Bárcena and *Radiolites mendozae* Bárcena. Mullerried (1930, p. 63) considers *H. mexicanus* to be of late Turonian age, and MacGillavry (1937, p. 101, 105) states that the Hippuritinae did not exist before late Turonian time.

39. At Pinos, Zacatecas, the upper Aptian, or lower Albian, is indicated by the occurrence of *Parahoplites*. Undoubtedly older Cretaceous beds are present, as the late Jurassic has been identified at the same place (Burckhardt, 1930, p. 81, 137).

40. Sandstone, shale, and shaly limestone, exposed at the northern base of a mountain south of Noria de Angeles in southeastern Zacatecas, are assigned to the basal Upper Cretaceous because they are stratigraphically higher than some chert-bearing limestone containing upper Albian ammonites (Böse, 1923a, p. 41).

41. The Taraises formation is an offshore limestone and marl facies of Berriasian to Hauterivian age and is widely distributed in north-central and eastern Mexico (Imlay, 1938a; 1940a). Wherever observed in the States of Durango, Coahuila, Zacatecas, San Luis Potosí, and Nuevo León, it comprises two distinct members that grade into each other through a narrow transition zone. The lower member consists mainly of compact, brittle, dark- to medium-gray, thick- to thin-bedded limestone, contains fossils of Valanginian and Berriasian ages, and makes a sharp contact with the underlying Upper Jurassic rocks at all localities. It apparently is unconformable on the Jurassic only near the old land masses, as in the Sierras de Parras and Jimulco of southern Coahuila and near Miquihuana, Tamaulipas (Imlay, 1936, p. 1145; 1937b, p. 552–559; 1937a, p. 605), where the basal beds are not older than Valanginian. The upper member consists of dark- to light-gray, thin- to medium-bedded limestone and marl, weathers characteristically light yellowish gray to cream color, and contains fossils of Hauterivian age. Its upper boundary is gradational into the overlying formation within a few feet. The lower Neocomian section in southwestern Tamaulipas and southernmost Nuevo León does not show the twofold division of the Taraises formation farther west and north but is in general so similar to the Taraises formation that a different name does not seem justified.

In north-central Mexico the Berriasian has been identified only in the Sierrita del Chivo near Symón, Zacatecas (Böse, 1923a, p. 91; Imlay, 1938a, p. 550), and near San Pedro del Gallo in eastern Durango (Burckhardt, 1912, p. 172–196). It is characterized by the ammonites *Spiticeras*, *Subthurmannia*, and *Protacanthodiscus*. The Valanginian has been identified at many localities and is characterized by the ammonites *Kilianella*, *Valanginites*, *Rogersites*, gigantic *Thurmannites*, *Dichotomites*, and many species of *Olcostephanus*. The lower Hauterivian is represented by a large ammonite fauna well developed in the lower part of the upper member of the Taraises formation. It is characterized by the ammonites *Maderia*, *Mexicanoceras*, *Acanthodiscus*, *Leopoldia*, *Neocomites*, *Distoloceras*, and many species of *Olcostephanus*. The upper Hauterivian in areas bordering the Coahuila Peninsula is probably represented by the Las Vigas sandstone, or the lower part of the Parritas formation. In offshore areas it is included in the upper part of the Taraises formation, because in the Sierrita del Chivo, near Symón, Zacatecas, the immediately overlying beds contain lower Barremian ammonites (Böse, 1923a, p. 102–118). The highest beds of the Taraises formation in the middle part of the Sierra de Parras (Imlay, 1938a, p. 551) contain species of *Olcostephanus*, *Distoloceras*, *Bochianites*, *Thurmannites*, and *Hemihoplites*(?) that are probably not younger than lower Hauterivian, but additional collecting and studies will be necessary before final conclusions can be drawn. An undoubted upper Hauterivian ammonite fauna has not yet been found in Mexico.

42. In the Sierra de Catorce of northern San Luis Potosí the Taraises formation is overlain by black, compact limestone containing the ammonites *Crioceras nolani* Kilian, *Paracrioceras*, *Barremites* aff. *B. difficile* (D'Orbigny), and *Pseudohaploceras*, which Burckhardt (1930, p. 136) considered of Barremian age.

43. The Cupido limestone comprises the offshore, thick- to thin-bedded limestone between the Taraises and La Peña formations (Imlay, 1937a, p. 606; 1938b, p. 1688, 1689). It is unfossiliferous in most places, but near Mazapil its lower part has furnished *Holcodiscus* and *Pseudohaploceras* (Burckhardt, 1930, p. 126). The former is strictly a Barremian genus, and the latter ranges from upper Barremian to upper Aptian. The age of the formation, on the basis of stratigraphic position, must range from early Barremian, or locally late Hauterivian, to early Aptian.

44. The La Peña formation consists of thick-bedded to shaly limestone and some shale and is distinguished from the contiguous formations by the presence of units of shaly to thin-bedded limestone. Its top in all sections is marked by a unit of thin-bedded limestone, marl, and shale that ranges from 50 to 300 feet in thickness, contains ammonites of late Aptian and earliest Albian age, and is one of the most widely developed, persistent lithologic units in central, northern, and eastern Mexico. The base of the La Peña formation is generally not sharply demarcated, and consequently the lower part of the formation at some localities probably includes older beds than at others. In the Sierra Jimulco the formation is extended down to the top of the Las Vigas formation, because there is no lithologic or faunal basis for subdivision at a higher level. Southward from the Sierra de Parras of southern Coahuila the formation becomes thinner and consists of thin-bedded limestone separated by shaly partings and many thin beds of black chert (Imlay, 1936, p. 1119–1124; 1937a, p. 607–611; 1938b, p. 1689–1690).

The basal part of the La Peña formation in the Sierra de Parras has furnished lower Aptian, or upper Barremian, ammonites including *Saynoceras mexicanum* Imlay (1940, p. 135, 161, Pl. 21, Figs. 1–4), *Parancyloceras*, *Ancyloceras*?, and *Hemicrioceras* (Imlay, 1937a, p. 611). The basal part of the formation near San Pedro del Gallo, Durango, has furnished *Holcodiscus*, a characteristic Barremian ammonite, and beds considerably higher have furnished *Costidiscus* similar to *C. recticostatus* D'Orbigny of the upper Barremian and lower Aptian (Burckhardt, 1912, p. 197, 198). The highest unit of the formation at many places in Mexico has furnished upper Aptian ammonites including particularly *Dufrenoya* and *Cheloniceras*. It has also furnished *Douvilléiceras* similar to *D. nodosocostatum* D'Orbigny of basal Albian age (1) at the southern end of the Sierra del Rosario and (2) near San Pedro del Gallo in eastern Durango (Burckhardt, 1925, p. 49–53) and (3) near Mazapil, Zacatecas (Burckhardt, 1906c, p. 197, 198; 1930, p. 134). The same unit along the southern side of the Sierra de Parras in southern Coahuila contains ammonites that apparently represent both the upper Aptian and basal Albian (Imlay, 1937a, p. 610; 1938b, p. 1664).

45. The Aurora limestone is a thick-bedded, massive, gray, rudistid-bearing limestone. In the Cuchillo Parado (type area) and Placer de Guadalupe districts of eastern Chihuahua, it is overlain by the Del Rio shale, underlain by limestone bearing *Orbitolina texana* Roemer, and is approximately equivalent, therefore, to the Georgetown limestone and the Fredericksburg group of Texas, or to the middle and upper Albian of the European sequence. In the Sierra de la Encantada, a few miles west of Placer de Guadalupe, about 16 feet of red marl and marly limestone, underlying a thick mass of rudistid-bearing limestone, has furnished *Oxytropidoceras*, *Exogyra texana* Roemer, *Gryphaea navia* Hall, and many other fossils (Böse, 1910b, p. 52, 53) of middle Albian age. This unit may be equivalent to the Kiamichi formation of Texas.

Elsewhere in Mexico the term Aurora limestone has been applied to rudistid-bearing limestone of early and middle Albian age that occurs over the site of the Coahuila Peninsula, in the high mountains bordering the former peninsula, and in a narrow strip along the Sierra Madre Oriental from the region of Saltillo southward. South of the Sierras de Parras and Jimulco in Coahuila and west of the Sierra del Rosario in eastern Durango, the Aurora limestone is replaced rather abruptly by thin-bedded, chert-bearing limestone that is included in the basal part of the Cuesta del Cura limestone. East of the Sierra de Bustamante in northwestern Nuevo León, the Aurora limestone is replaced by a dense, thick-bedded limestone without rudistids (Böse and Cavins, 1927, p. 23, 24). The Aurora limestone is interpreted as a reef facies of Albian age deposited over, or near, areas that were landmasses in Late Jurassic or Neocomian time (Imlay, 1938b, p. 1690, 1691).

46. The Indidura formation has been discussed as follows (Imlay, 1938, p. 1691–1692):

"*Indidura, Cuesta del Cura, and Caracol formations.*—The Indidura formation was originally defined (Kelly, 1936, p. 1028–1029) for about 100 feet of shales, rubbly limestones, and platy limestones directly overlying the Aurora limestone at the southern end of the Sierra de Santa Ana southwest of Las Delicias, Coahuila. The type section contains fossils of upper Albian, Cenomanian, and Turonian ages (Jones, 1938, p. 86–93). The same facies and fauna directly overlie the Aurora limestone in the Sierra de la Peña (Jones, 1938, p. 83–86) and in the Sierra de Tlahualilo (Robinson).

All these areas overlie, or are on the margin of, the Coahuila Peninsula of Upper Jurassic time. South of the site of the peninsula in southern Coahuila and northern Zacatecas the Indidura formation becomes more calcareous and very unfossiliferous. In the western part of the Sierra de Parras it is of Cenomanian, Turonian, and Coniacian age and is underlain by the Cuesta del Cura limestone which is probably equivalent to the basal Indidura at its type locality. In the middle part of the Sierra de Parras and farther south in Coahuila and northern Zacatecas the Indidura is underlain by the Cuesta del Cura limestone and overlain by the Caracol shale and tuff. The latter thickens greatly southward and is equivalent to the upper part of the Indidura formation of the western part of the Sierra de Parras. Thus, the Indidura formation in central Coahuila passes southward in Coahuila and Zacatecas into three distinct facies. In central Coahuila, over the site of the Coahuila Peninsula, deposition went on very slowly in a shallow sea from Upper Albian until Coniacian time and the environment remained very favorable for bottom-living organisms. South of the peninsula, deposition occurred in fairly deep waters during the upper Albian and in shallow waters during Cenomanian to Coniacian time, but the bottom conditions were unfavorable to organisms, probably due to the rapid accumulation of sediments derived from the rising landmasses in central Mexico. The maximum thickness of the Indidura formation on areas overlying Coahuila Peninsula is only a few hundred feet. The thickness of equivalent formations in northern Zacatecas is more than 4000 feet. Comparing the highly fossiliferous Indidura formation in central Coahuila with the unfossiliferous so-called Indidura formation in areas off-shore from the Coahuila Peninsula, the question arises as to whether they should be recognized by the same name. Perhaps future studies of the formation will show the desirability of restricting the name to the deposits overlying the Coahuila Peninsula and of giving a different name to the deeper-water facies."

Beds comparable lithologically, faunally, and stratigraphically with the Indidura formation in the Sierra de Santa Ana have been identified in west-central and southwestern Coahuila in the Sierra de la Peña, on Cerro del Macho near Mohóvano, and near Piedra de Lumbre. These areas are on, or marginal to, the site of the Coahuila Peninsula of Jurassic-Neocomian time.

The so-called Indidura formation in areas offshore from the Coahuila Peninsula in eastern Durango, southernmost Coahuila, Zacatecas, eastern Coahuila, and west-central Nuevo León consists of alternating beds of dark shale, shaly limestone, and thinly laminated, platy limestone. It is mainly of late Cenomanian and Turonian age, although locally, as in the western part of the Sierra de Parras, beds of Coniacian age have conveniently been included (Imlay, 1936, p. 1127, 1128, 1132). It is nearly identical with the Agua Nueva formation of eastern Mexico and with the flaggy limestone facies of the Eagle Ford formation of northernmost Coahuila and Nuevo León and might appropriately be called by either name. Like them, it has furnished very few fossils other than *Inoceramus* and fish scales.

West of the site of the Coahuila Peninsula in (1) the Sierra Mojada, in (2) the Santa Elena area, and in (3) the lower part of the valley of the Río Conchos, all in eastern Chihuahua, occurs a fairly thick, highly fossiliferous shale and marl facies which Vivar (1925, p. 6) called the Ojinaga formation, and which Adkins (1933, p. 426, 437), on the basis of exposures in western Jeff Davis County, Texas, called the Chispa Summit formation. The term Ojinaga formation was originally applied by Burrows (1910, p. 101, 102) to the entire Cretaceous sequence above the Aurora limestone but was adequately redefined by Vivar. As pointed out by Adkins, the Ojinaga (Chispa Summit) formation contains an abundant ammonite fauna of late Cenomanian to late Turonian age.

The basal marls of the Upper Cretaceous near San Pedro Conchos in central Chihuahua are reported (Waitz, 1928, p. 246, 247) to contain many intercalations of sandstone, which may indicate that the shore line was not much farther west.

47. The Parras shale consists of about 5000 feet of calcareous, dark-gray to black, fissile to nodular shale, the lower part of which contains widely spaced beds of calcare-

ous sandstone, or tuff, which becomes more common southward (Imlay, 1936, p. 1132, 1133; 1937a, p. 619, 620; 1938b, p. 1167, 1692). It crops out along the south side of the Parras Basin in southern Coahuila, along the south side of the Sierra de Parras in southeastern Coahuila, at many places in northern Zacatecas, and has been identified in the area between Monterrey and Saltillo (Humphrey, 1941, p. 1). On the basis of stratigraphic position it is correlated with the upper part of the Austin chalk of Texas and must be mainly of Santonian age but may represent part of the Coniacian. In the Parras Basin it is underlain by beds containing *Peroniceras* of Coniacian age and overlain by beds containing *Exogyra ponderosa* Roemer and *Placenticeras*.

48. The Difunta formation consists of at least 12,000 feet of shale, shaly to thin-bedded sandstone, thick-bedded sandstone, and many beds of limestone conglomerate. It has been identified definitely only in the Parras Basin and in the area between Monterrey and Saltillo. In the El Pozo-Boquillas area it has furnished a large fauna of the *Exogyra ponderosa* zone, including such diagnostic fossils as *Inoceramus oblongus* Meek, *I. pertenuis* Meek and Hayden, *Ostrea saltillensis* Böse, *Exogyra ponderosa* Roemer, *E. costata* var. *spinifera* Stephenson, *Liopistha* (*Cymella*) *bella* Conrad, *Gyrodes spillmani* Gabb, and *Placenticeras* sp. (Imlay, 1936, p. 1133–1135; 1937c). Near General Cepeda and Saltillo its upper part has furnished *Exogyra costata* Say and *Sphenodiscus*.

49. The Maestrichtian is represented in northeastern Coahuila between Eagle Pass and Las Esperanzas by the Escondido formation above and the Olmos formation below. The Escondido formation consists of varicolored sandstone, shale, conglomerate, and sandy limestone about 750 feet thick and is characterized by the fossils *Exogyra costata* Say and *Sphenodiscus*. The Olmos formation consists of clay, shale, sandstone, and coal about 885 feet thick, does not contain marine fossils, and probably has disconformities at both top and bottom (White, 1883, p. 207; 1891, p. 130–140; Dumble, 1892; Vaughan, 1900; Ludlow, 1906; Aguilera, 1906b; Schwartz, 1912; Böse, 1923b, p. 334; Jones, 1925; Mullerried, 1927, p. 11; Stephenson, 1915, p. 169–176; 1931; Böse and Cavins, 1927, p. 37–56, 101–107; Burckhardt, 1930, p. 244–258; Tatum, 1931, p. 872–877; Kane and Gierhart, 1935, p. 1360–1364). Farther southeast in the area between Lampazos and Saltillo the coal-bearing Olmos formation is not present, and its position is occupied either by marine beds containing *Exogyra costata* Say or by the Tulillo beds containing a brackish-water fauna. Böse and Cavins (1927, p. 37–40) claim that the Tulillo beds extend from El Pescado, near Laguna de la Leche, south-southwest to Saltillo, but, as they found brackish-water fossils only near Lampazos and El Pescado, the existence of the Tulillo beds over such a large area may be questioned. Detailed correlation of the Maestrichtian beds between Lampazos and Saltillo will not be possible until additional field studies are made.

50. The Caracol formation consists of devitrified tuffs, shale, and small amounts of limestone, occurs in the large synclinal valleys from the middle part of the Sierra de Parras southward at least as far as Mazapil, and thickens southward from about 900 feet to more than 3000 feet. The thickening corresponds with an increase in the amount of tuffaceous material. It grades westward along the southern edge of the

Parras Basin of southern Coahuila into a shale and limestone facies without tuff which, near Parras, is included in the upper part of the Indidura formation and contains the ammonite *Peroniceras* (Imlay, 1937a, p. 616–619; 1938b, p. 1666, 1667, 1691).

51. South of Opal in northwestern Zacatecas the Indidura formation is overlain by an enormous thickness of yellow, red, and green sandstone, alternating with gray, marly shale, and some beds of gray limestone. In the absence of fossils, these sandy beds can only be determined as Upper Cretaceous younger than Turonian (Böse, 1923a, p. 45, 46).

52. The Parritas limestone in the western part of the Sierra de Parras (Imlay, 1936, p. 1117–1119) and in the mountains west of the Laguna district in eastern Durango (Imlay, 1938b, p. 1688; 1940a, p. 123, 124) consists mainly of yellowish to reddish, thin- to thick-bedded limestone directly overlying the Las Vigas formation. Similar limestone overlying the Taraises formation in the Sierrita del Chivo in northern Zacatecas contains the ammonites *Pulchellia* and *Pseudohaploceras* and is, therefore, of Barremian age (Böse, 1923a, p. 26–29, 102–118). Similar limestone near San Pedro del Gallo contains *Leptoceras*, overlies the Taraises formation which contains lower Hauterivian ammonites, and underlies gray, thick-bedded limestone whose lower part contains *Holcodiscus*, a characteristic Barremian ammonite (Burckhardt, 1910, p. 326, 327; 1930, p. 129, 132).

53. The Las Vigas formation exposed in the Placer de Guadalupe and Cuchillo Parado districts of the Conchos Valley of eastern Chihuahua has not furnished determinable fossils but must be of Neocomian age, as it overlies Upper Jurassic beds and underlies the Cuchillo formation that contains upper Aptian fossils near its top. The Las Vigas formation as described by Burrows (1910, p. 93) consists of four distinct members, which, from top to bottom, are as follows:

	Feet
4. Sandstone, gray to reddish, thin-bedded, alternating with shale; some beds of gypsum and limestone near top. Contains small *Exogyra* and plant remains	750
3. Shale, black to red	240
2. Sandstone, calcareous, gray to reddish	700
1. Limestone, sandy	250

In southern Coahuila and eastern Durango the Las Vigas formation of current usage includes the clastic facies deposited around the margin of the Coahuila Peninsula during upper Neocomian time (Imlay, 1936, p. 1115–1117; 1938b, p. 1687–1689; 1940a, p. 124; Kellum, 1936a, p. 1058, 1070), but it is probably equivalent to only the upper part of the Las Vigas formation of the Conchos Valley.

54. The Cuchillo formation exposed in the lower part of the Conchos Valley of eastern Chihuahua comprises two members. The upper member consists of about 500 feet of shale, shaly limestone, and some sandstone, and contains upper Aptian ammonites including *Dufrenoya* and *Cheloniceras*. The lower member consists of 1500 feet of white, granular gypsum and shale in variable proportions and locally near the base includes some rock salt (Burrows, 1910, p. 95, 96). It is probably of early Aptian age.

A similar section of the Cuchillo formation consisting of thin-bedded limestone and shale of earliest Albian-late Aptian age underlain by gypsiferous beds is exposed

about 100 miles to the southeast in the Santa Elena district of easternmost Chihuahua. Farther southeast in Coahuila is a widespread, gypsiferous facies of Aptian to middle Albian age (Kellum *et al.*, 1936, p. 983–986), but the principal mass of gypsum appears to be of Albian age corresponding in stratigraphic position with the Ferry Lake anhydrite of Arkansas, Louisiana, and northeast Texas. In the well-described section exposed in the Sierra de Santa Ana about 15 miles west of Las Delicias (Kelly, 1936, p. 1022–1029; Jones, 1938, p. 86–93), the gypsiferous mass of the upper Cuchillo formation is overlain by the rudistid-bearing Aurora limestone, whose upper boundary corresponds with that of the Edwards limestone of Texas, and is underlain by the lower Cuchillo formation of earliest Albian-late Aptian age. The lower Cuchillo formation comprises two members. The upper member consists of 100 to 200 feet of massive limestone and contains *Orbitolina texana* (Roemer). The lower member consists of 50 to 100 feet of interbedded limestone, shale, sandstone, and conglomerate, contains Trinity mollusks including *Dufrenoya* and *Douvilleiceras*, and is sharply demarcated from the underlying Permian.

The stratigraphic position of the gypsiferous upper Cuchillo formation corresponds, therefore, with the upper part of the Glen Rose formation of Texas and represents the low middle Albian or high lower Albian, or both.

In conclusion, the Cuchillo formation as currently understood is a gypsiferous facies of early Aptian to middle Albian age deposited over, or near, the site of the Coahuila Peninsula. The main mass of gypsum near the margin of the peninsula, as at Cuchillo Parado and Santa Elena in Chihuahua and perhaps at Potrero de Menchaca in east-central Coahuila (Imlay, 1940a, p. 121, 122) is of early Aptian age, but over the peninsula it is of late early or middle Albian age. The upper Aptian and basal Albian are represented mainly by a thin-bedded limestone and shale facies comparable lithologically and faunally with the upper member of the La Peña formation and are not known definitely to be represented by gypsiferous deposits.

55. The Carbonera formation includes from 740 to 1300 feet of shaly sandstone and shale overlying Jurassic beds and underlying the Taraises formation in the mountains west of the Laguna District in eastern Durango (Imlay, 1938b, p. 1687–1689; 1940a, p. 123, 124, 133, 134). Its middle part is characterized by the presence of *Exogyra reedi* Imlay, giant species of *Thurmannites* similar to *T. novihispanicus* Imlay, and *T. miquihuanensis* Imlay from the Miquihuana area of Tamaulipas. These forms of *Thurmannites* probably represent the middle Valanginian. The lower part of the formation has furnished distorted ammonites probably belonging to *Spiticeras* and *Thurmannites* (Imlay, 1940a, p. 133, 134) and suggesting a Berriasian age.

56. Near Parral and Jiménez, Chihuahua, some dark shale and thin beds of limestone have furnished uncoiled ammonites characteristic of the upper Albian of Mexico (Waitz, 1906, p. 2–5; Burckhardt, 1930, p. 174). Near Cañas, about 23 miles southeast of Jiménez, Böse (1910b, p. 50, 128, 132, 152) found pelecypods and echinoids that occur elsewhere in the Fredericksburg group and probably represent the middle Albian.

57. The Patula arkose at Barril Viejo in eastcentral Coahuila consists of about 1,500 feet of green and brown arkoses directly underlying marly beds containing the

upper Aptian ammonite, *Dufrenoya texana* Burckhardt, and directly overlying the thin Padilla limestone which cannot be younger than Barremian (Imlay, 1940a, p. 121, 122). In the Sierra Mojada of southeastern Chihuahua the thin-bedded limestone and shale of the upper Aptian is underlain by about 1,000 feet of conglomeratic sandstone and coarse conglomerate whose particles consist of rhyolite, granite, basalt, and some limestone. Arkosic beds of considerable thickness and at a similar stratigraphic position have been penetrated by drilling in northern Coahuila in the area west of Del Rio, Texas. The Patula arkose at Barril Viejo grades northward and eastward into the La Mula shales, which consist of gray, green, pink, purple, and yellow shale and sandy shale (Imlay, 1940a, p. 122, 123). Red shale beneath the upper Aptian beds of the Sierra del Carmen area in northwestern Coahuila is probably equivalent.

58. Near Soledad and along the railroad between Escalón, Chihuahua, and Sierra Mojada, Coahuila, occur beds consisting of red, green, and gray marl overlain by sandstone, conglomerate, shale, and sandy shale. The sandstones are locally cross-bedded. The conglomerate contains fragments of limestone, andesite, rhyolite, and the remains of dinosaurs and silicified trees (Haarmann, 1913, p. 25). Burckhardt (1930, p. 259) correlates these beds with the dinosaur-bearing beds of late Late Cretaceous age in the Big Bend area of Texas (Adkins, 1933, p. 508, 509).

In the Santa Elena area of eastern Chihuahua, about 50 miles north of Sierra Mojada, a specimen of reddish-yellow, calcareous sandstone, obtained at least 2000 feet stratigraphically above beds of Turonian age, contains *Baculites* and *Turritella trilira* Conrad of Taylor or Navarro age. The sandstone possibly corresponds with the beds near Soledad at the corner of Chihuahua, Durango, and Coahuila, or with the Difunta formation of the Parras Basin of southern Coahuila.

59. The beds of Albian age in the Santa Elena area as described by F. L. Wingfield in an unpublished report appear to be very different from beds of the same age in the Sierra Mojada, about 50 miles to the south, or in the lower part of the valley of the Río Conchos, about 100 miles to the northwest. The upper Albian, or Georgetown equivalent, consists of 525 meters of limestone and shale that basally contain species of *Prohysteroceras* of Duck Creek or Fort Worth age. Directly beneath is 155 meters of shale, marl, and thin-bedded limestone containing *Oxytropidoceras*, *Hysteroceras*, *Beudanticeras*, and *Lechites* of middle Albian age. Beneath these beds is 305 meters of thin-bedded limestone and shale and then 505 meters of thin- to medium-bedded limestone containing a few chert nodules but no fossils. These rest on thin-bedded limestone and shale of the Cuchillo formation, whose highest beds contain ammonites of earliest Albian, or late Aptian age. The thicknesses given would seem more accordant with those of other areas if they were in feet rather than in meters. Interestingly, there does not appear to be any limestone to which the name Aurora may be applied.

60. The Padilla limestone is thick-bedded, dark gray, thickens from about 50 feet at Barril Viejo and Potrero de Menchaca to about 550 feet at Potrero de Oballos, and on the basis of stratigraphic position is probably of Barremian age. The Barril Viejo shale is mainly dark gray and calcareous, ranges from 100 to 840 feet in thickness, and contains a large fauna of middle Neocomian age, including species of *Leo-*

poldia and *Acanthodiscus* that furnish a definite correlation with the upper member of the Taraises formation of the central part of the Mexican geosyncline. The San Marcos arkose contains boulders of granite as much as 30 inches in diameter, ranges from 400 to 700 feet in thickness, and probably represents a very small time interval. It passes eastward at Potrero de Oballos into 204 feet of shale and fine-grained sandstone. The Menchaca limestone is thick-bedded, dark gray, attains a thickness of 1743 feet at Potrero de Menchaca, and contains *Exogyra reedi* Imlay and *E. putnami* Imlay that are common in beds of Valanginian age near Miquihuana, Tamaulipas. The underlying 557 feet of brown and gray shale and sandy shale at Potrero de Menchaca contains the same species of *Exogyra* and is consequently assigned to the basal Cretaceous rather than to the Upper Jurassic (Imlay, 1940a, p. 121–123, 127, 128, 131–133).

61. The Coniacian and Santonian stages are represented in northern Coahuila and northwestern Nuevo León by about 1300 feet of chalky, marly, and shaly limestone (Böse and Cavins, 1927, p. 31–34; Burckhardt, 1930, p. 225–227) that Dumble (1915, p. 170) named the San Juan limestone, but which may satisfactorily be called the Austin chalk. A similar limestone and marl facies exists in east-central Coahuila between Monclova and Cuatro Ciénegas, but changes southward in southern Coahuila into the much thicker Parras shale and the upper part of the Indidura formation of offshore facies (Imlay, 1936, p. 1132, 1133). In eastern Nuevo León and northern Tamaulipas, the Austin limestone and marl facies is replaced by calcareous shale that is included in the lower part of the Mendez (Papagayos) shale (Böse and Cavins, 1927, p. 68, 69; Burckhardt, 1930, p. 227). These relationships show that the Austin chalk (San Juan limestone) is separated geographically from the somewhat similar San Felipe limestone of east-central Mexico by a thick shale facies. The upper fourth of the Austin chalk of northern Mexico has furnished *Texanites texanum* (Roemer), *Canadoceras flaccidicostum* (Roemer), *Baculites*, and large *Inoceramí* and is correlated with the Santonian. The lower three-fourths has furnished *Peroniceras*, *Gauthiericeras* cf. *G. margae* (Schlüter), *Barroisiceras* aff. *B. haberfellneri* (Hauer), and giant *Inoceramí* related to *Inoceramus undulatoplicatus* Roemer (Burckhardt, 1930, p. 225–227).

62. In the Sierra de Lampazos of northern Nuevo León are exposed beds of middle and late Albian age (Böse and Cavins, 1927, p. 23, 24) that differ considerably from equivalent beds in the Sierras de Bustamante and Azul, a short distance to the west. At the top is about 492 feet of thin-bedded limestone and marl containing *Pervinquieria* and comparable with the Georgetown limestone of Texas rather than the Cuesta del Cura limestone to the west. Directly below is about 328 feet of reddish-gray marl and thin-bedded limestone containing *Oxytropidoceras* and probably equivalent to the Kiamichi formation of Texas. Below follows about 1640 feet of hard, thick-bedded limestone containing *Hoplites*, but no rudistids, and resembling the Tamaulipas limestone of Tamaulipas rather than the Aurora limestone in the next mountains to the west.

63. A complete Comanche section about 4440 feet thick was penetrated by the Mexican Gulf Oil Company's San Ambrosio no. 1 well about 52 km. S. 45° W. of Laredo, Texas, in northern Nuevo León. The Buda limestone is 100 feet thick, the Del Rio shale is 70 feet thick, the Georgetown-Edwards limestone is 960 feet thick,

and all three are similar to the same formations exposed on the outcrop in south-central Texas. Below follows a sequence of shale and limestone unlike any known Texas section, but more like sections in the central part of the Mexican geosyncline. At the top is 810 feet of black shale interbedded with brittle limestone that slightly below the middle has furnished *Parahoplites*. This unit is probably equivalent to both the Glen Rose and Travis Peak formations of Texas, and its basal part is probably of late Aptian age. Below follows 390 feet of hard, dense, brittle limestone, and then 1210 feet of interbedded black shale and limestone which must represent the lower Aptian and Barremian. The underlying 760 feet of black shale and marly limestone contains Neocomian ammonites assigned by Burckhardt to *Bochianites*, *Hoplites* (?), and *Crioceras* and may be correlated with the Barril Viejo shale of east-central Coahuila and the upper member of the Taraises formation farther south. The basal 240 feet of hard, brittle limestone may be correlated with the Menchaca limestone of east-central Coahuila and the lower member of the Taraises formation. It overlies Upper Jurassic shale containing *Kossmatia*.

64. The Comanche section exposed in the Sierra del Burro includes rocks as old as upper Aptian (Böse and Cavins, 1927, p. 19, 23, 24, 26–28, 83, 85, 89–91; Cumming, 1928, p. 11–14; Burckhardt, 1930, p. 147, 188–190; Adkins, 1933, p. 298, 392; Burckhardt and Mullerried, 1936, p. 320) and is essentially the same as in south-centra Texas. The Del Rio clay passes southward into hard, thin-bedded limestone similar to the Buda limestone. The Georgetown limestone becomes harder westward and passes into the rudistid facies called the Devils River limestone. Between the Georgetown and Edwards limestone is a unit of dark shaly limestone including some dolomite lenses that probably is the Kiamichi formation. The Edwards limestone is underlain by 50 feet of marl containing many specimens of *Exogyra texana* Roemer and occupying the same position as the Comanche Peak and Walnut formations of Texas. The Glen Rose limestone is about 2000 feet thick and is underlain by a unit of shaly limestone and shale containing the ammonite *Cheloniceras* of probable late Aptian age. The latter unit is underlain in the subsurface by arkose or red shale. On the whole, the Comanche section is very similar to that encountered in the Amerada Oil Company's Halff and Oppenheimer no. 8 well in Frio County, Texas.

65. The San Miguel formation and Upson clay appear to be essentially identical with the same formations in Maverick County, Texas (Stephenson, 1931; Adkins, 1933, p. 467–472).

66. In the Sierra del Carmen area of northwestern Coahuila the upper Aptian shaly beds are overlain by about 1640 feet of gray, massive limestone representing the Albian and perhaps part of the Cenomanian (Cumming, 1928, p. 11–14; Burckhardt, 1930, p. 187).

67. In the Sierra del Carmen area the beds equivalent to the Taylor marl consist of shale, marl, and calcareous sandstone containing *Exogyra ponderosa* Roemer and *Placenticeras planum* Hyatt (Cumming, 1928, p. 16; Burckhardt, 1930, p. 224–225).

68. The presence in the Cuchillo Parado-Aldama area of Glen Rose limestone bearing *Orbitolina texana* Roemer and caprinids has been noted by Vivar (1925, p. 6; Burckhardt, 1930, p. 187). This limestone, as well as the Del Rio shale and Buda limestone were overlooked by Burrows (1910).

69. In the Ojinaga area of eastern Chihuahua the Upper Cretaceous section above

beds of Turonian age includes the equivalents of the Austin, Taylor, and probably the Navarro of Texas but have scarcely been studied. Above the bituminous shale and limestone of Turonian age is a reddish sandstone and sandy shale containing *Peroniceras* aff. *subtricarinatum* D'Orbigny and *Proplacenticeras* aff. *P. fritschi* Grossouvre which furnish a correlation with the lower part of the Austin chalk. Above follows sandy shale and marl containing *Texanites texanus* (Roemer) of late Austin age. Above follows very sandy shale interbedded with many beds of limestone containing species of *Placenticeras* of Taylor age. At the top occurs sandstone and conglomerate of possible Navarro age. Beds of coal near the city of Ojinaga are considered to be of Taylor age (Böse and Cavins, 1927, p. 35, 68, 95, 98, 99, 103; Burckhardt, 1930, p. 239; Adkins, 1933, p. 509).

70. The Comanche section on Cerro Muleros a few miles west of El Paso, Texas, has been examined by several geologists (Stanton and Vaughan, 1896; Böse, 1910b; Böse and Cavins, 1927, p. 149, 152; Burckhardt, 1930, p. 179–185, 218; Adkins, 1933, p. 339, 355, 362, 368, 369, 373, 380, 382, 385, 393, 399, 431), but the part equivalent to the Georgetown limestone needs a careful restudy. The Buda and Del Rio formations at the top and the Edwards (Finlay) limestone near the base are easily recognized. The Kiamichi formation is sandier than in eastern Texas but carries a typical Fredericksburg fauna. As now interpreted, the equivalent of the Duck Creek formation consists of 100 to 165 feet of shale characterized by *Prohysteroceras whitei* Böse, *Leonites nodosum* (Böse), and *Pervinquieria trinodosum* (Böse). The equivalents of the Denton and Fort Worth formations consist of 100 to 165 feet of marl and nodular limestone characterized by similar ammonites and an abundance of *Gryphaea washitaensis* Hill. The equivalents of the Pawpaw and Weno formations consist of 35 to 75 feet of shale alternating with brown, flaggy sandstone characterized by *Lopha quadriplicata* (Shumard), *Lopha subovata* (Shumard), *Gryphaea washitaensis* Hill, and basally by *Neokentroceras* and *Pervinquieria*. The equivalent of the Main Street limestone consists of 75 to 330 feet of reddish, hard, thick-bedded sandstone that in its upper part bears shaly layers characterized by *Exogyra arietina* Roemer, *Exogyra whitneyi* Böse, and *Hemiaster calvini* Clark.

71. The Comanche section near Arivechi, Sonore, as described by King (1939, p. 1660–1673) is over 10,000 feet thick and entirely of Trinity and Fredericksburg age. The Potrero formation consists of about 5200 feet of shale, marl, thin-bedded, sandy limestone, some interbedded andesite, and agglomerate, and contains many Fredericksburg fossils including *Engonoceras gabbi* Boehm, *Exogyra texana* Roemer, and *Lunatia? pedernalis* (Roemer) (Gabb, 1869; Burckhardt, 1930, p. 176, 177). The underlying Palmer formation is about 4550 feet thick. Its lower 1000 feet consists of coarse conglomerate, and its upper 3550 feet consists mainly of limestone interbedded with some shale, sandstone, and quartzite. A *Phylloceras* of Albian type was obtained from its lower third. King (1939, p. 1673–1676) shows that westward from Arivechi the Comanche changes mainly to a clastic and volcanic facies which west of the Río Yaqui overlies continental beds of latest Triassic or possibly early Jurassic age. The name "Potrero" is preoccupied by the Lower Jurassic marine shale of southeastern Mexico (Böse, 1898, p. 175), so another name should be proposed for the beds near Arivechi.

UPPER CRETACEOUS FOSSIL LOCALITIES IN CENTRAL AMERICA AND MEXICO

72. The Comanche section at the head of Cañón de Santa Rosa, near El Tigre in the Sierra de Teras consists of about 2845 feet of alternating units of limestone, sandstone, and shale, is conglomeratic basally, and rests on Permian limestone (Imlay, 1939b, p. 1733–1735). *Exogyra quitmanensis* Cragin occurs throughout most of the section and is evidence of its Trinity age. About 565 feet above the base is a thick unit of shale that has furnished *Parahoplites* cf. *P. uhligi* Anthula, *Beudanticeras*, *Acanthoplites*, *Cheloniceras* cf. *C. cornueli* (D'Orbigny), and *Exogyra quitmanensis* Cragin. A late Aptian, rather than an early Albian, age is favored by the presence of species similar to *Parahoplites uhligi* and *Cheloniceras cornueli* and by the absence of *Orbitolina*, which is so characteristic of beds of early and middle Albian age in the southern United States.

73. The formations of the Bisbee group exposed around the margins of the Cabullona basin (Dumble, 1900, p. 135–137; Burckhardt, 1930, p. 177, 178; Taliaferro, 1933, p. 19–22; King, 1939, p. 1676, 1677, Pl. 5; Imlay, 1939b, p. 1736–1739) differ from those in the Bisbee district (Ransome, 1904, p. 56–73; Tenney, 1932, p. 46; Stoyanow, 1938, p. 117) by being considerably thicker but are undoubtedly of the same age and probably entirely Trinity. That later Comanche rocks were once present is shown by the occurrence of (1) *Exogyra arietina* Roemer on the summit of the next to the highest peak in the Huachuca Mountains about 20 miles west of Bisbee, and (2) *Stoliczkaia* in the Patagonia Mountains still farther west (Stoyanow, 1938, p. 117).

74. The Cabullona group (Taliaferro, 1933, p. 25–32) probably represents the highest Upper Cretaceous as indicated by the presence of duckbill dinosaur bones near the top of the Snake Ridge formation and by the fact that in North America thick conglomerates are uncommon in Upper Cretaceous beds older than Campanian.

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U. S. Geological Survey, Washington, D. C.

Manuscript Received by the Secretary of the Society, February 10, 1944.
Published with the Permission of the Director, U. S. Geological Survey.

GENERALIZED STANDARD SECTIONS				CHARACTER
SERIES		EUROPEAN STAGES	TEXAS AND MEXICO	AMMONITES
			OVERLYING ROCKS	
UPPER CRETACEOUS	GULF	DANIAN	HIATUS	
		MAESTRICHTIAN	NAVARRO	
		CAMPANIAN	TAYLOR	Placenticeras cf. P. meeki
		SANTONIAN	AUSTIN	Texanites texanus and Canadoceras flaccidiscatum
		CONIACIAN		Gauthiericeras cf. G. margae; Barroisiceras cf. B. haberfelli and Peroniceras aff. P. subtricarinatum
		TURONIAN	EAGLE FORD	Prionotropis aff. P. hyatti and abundant Collignoceras; Prionotropis cf. P. woolgari and abundant Romaniceras; Vascoceras, Fagesia, Neoptychites and Metoicoceras cf. M. whitei; Mantelliceras aff. M. cauloni and Acanthoceras spp.
		CENOMANIAN	WOODBINE	Sharpeiceras sp.
LOWER CRETACEOUS	COMANCHE		?	Budaiceras ? Mantelliceras cf. M. mantelli; Adkinsia; Turrilites brazoensis; Stoliczkaia; Pachydiscoceras
		ALBIAN	WASHITA	Parvinquieria maxima; Desmoceras brazoense; Oxytropidoceras bonnapi; Dipoloceras cristatum; Oxytropidoceras acuticarinatum; Knemiceras; Douvilleiceras mamillatum; Sonneratia
			FREDERICKSBURG	
		APTIAN	TRINITY	Douvilleiceras cf. D. nodosocostatum; Dufrenoya texana and Pedioceras, Ammonitoceras, Procheloniceras; Acanthohoplites; Colombiceras
	COAHUILA	NEOCOMIAN BARREMIAN	NUEVO LEÓN	Pseudohaploceras; Parancyloceras; Heteroceras; Barremites; Pulchellia
		NEOCOMIAN HAUTERIVIAN	DURANGO	Olcostephanus sp. Olcostephanus raricostatus and Leopoldia, Acanthodiscus cf. A. radiatus
		NEOCOMIAN VALANGINIAN		Rogersites, Valanginites, and Dichotomites; Thurmannites miquihuanensis and T. novihispanicus
		NEOCOMIAN BERRIASIAN		Berriasella, Subthurmannia, Spiticeras, Himalayites, Protacanthodiscus, and Neocomoceras.
			UNDERLYING ROCKS	

CHARACTERISTIC FOSSILS

IONITES

OTHER FOSSILS

Tampsia and Titanosarcolites

Coralliochama g. beckmi

Sphaerodiscus

Placenticeras cf. P. meeki

Texanites

Sauvagesia cf. S. degolyeri

Inoceramus undulatoplicatus

Exogyra costata

Exogyra spatulata

Exogyra ponderosa

Exogyra arietina

Ostrea lugubris

Hippurites mexicanus

Inoceramus cf. I. fragilis

Inoceramus labiatus bohemi

Exogyra cf. E. olisiponensis

Cyphosoma radiosum

Exogyra arietina var. coahuilensis

Coelocamena ramosa

Pecten roemeri

Exogyra carrilloi

Exogyra arietina

Stenic-laia

Prohaplitoceras

Pseudohaploceras

Inoceramus subsulcatiformis, Toucasia texana, T. patagiata

Exogyra texana

Cryptaulax morchoba

Orbitolina texana

Exogyra quitmanensis

Acanthopites

Columbiceras

Hypacanthoplites

Lyelliceras

Pseudohaploceras

Holcodiscus

Barremites

Crioceratites cf. C. reticostatus

Olcostephanus

Exogyra reedi

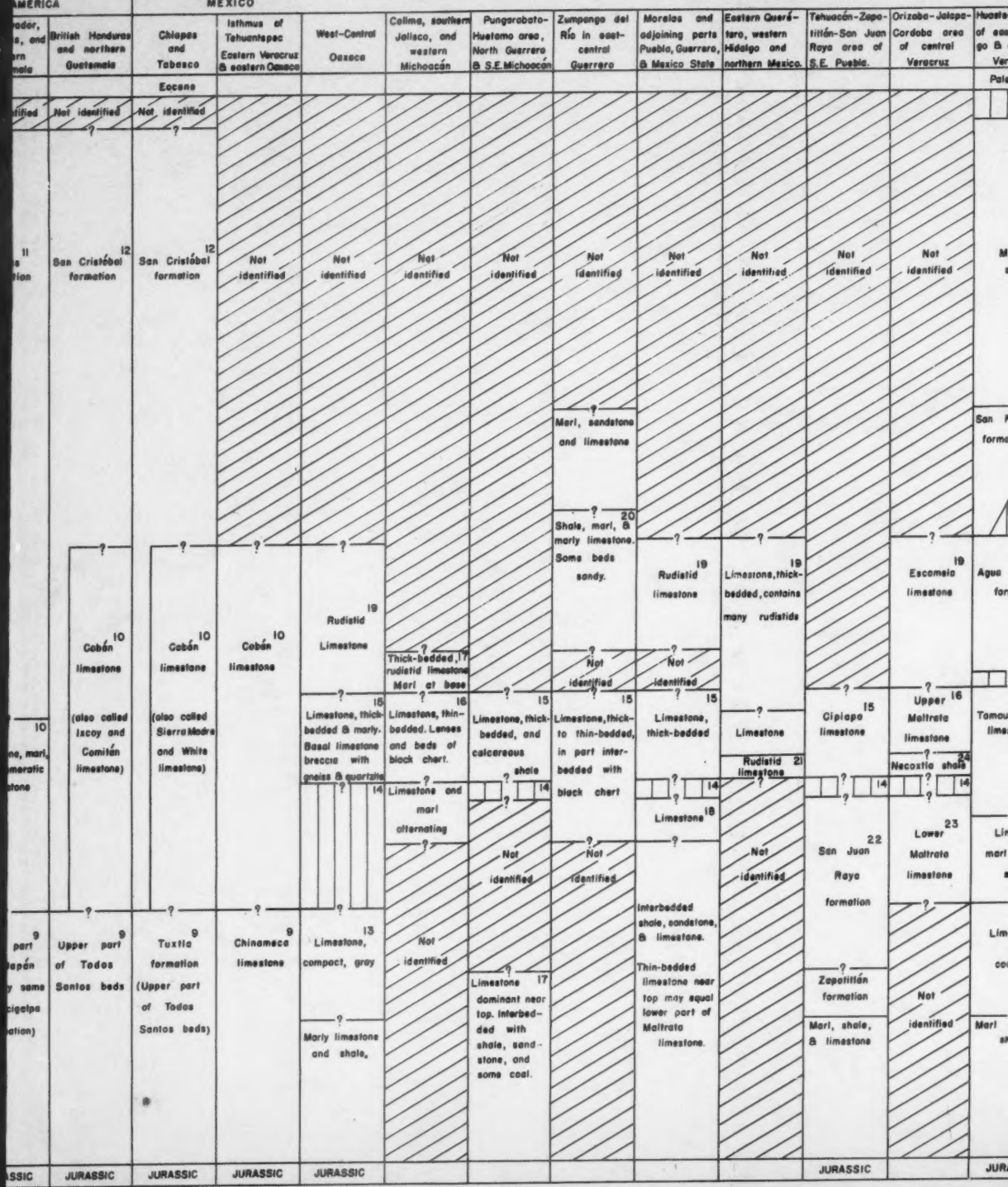
GREATER ANTILLES

CENTRAL AMERICA

MEXICO

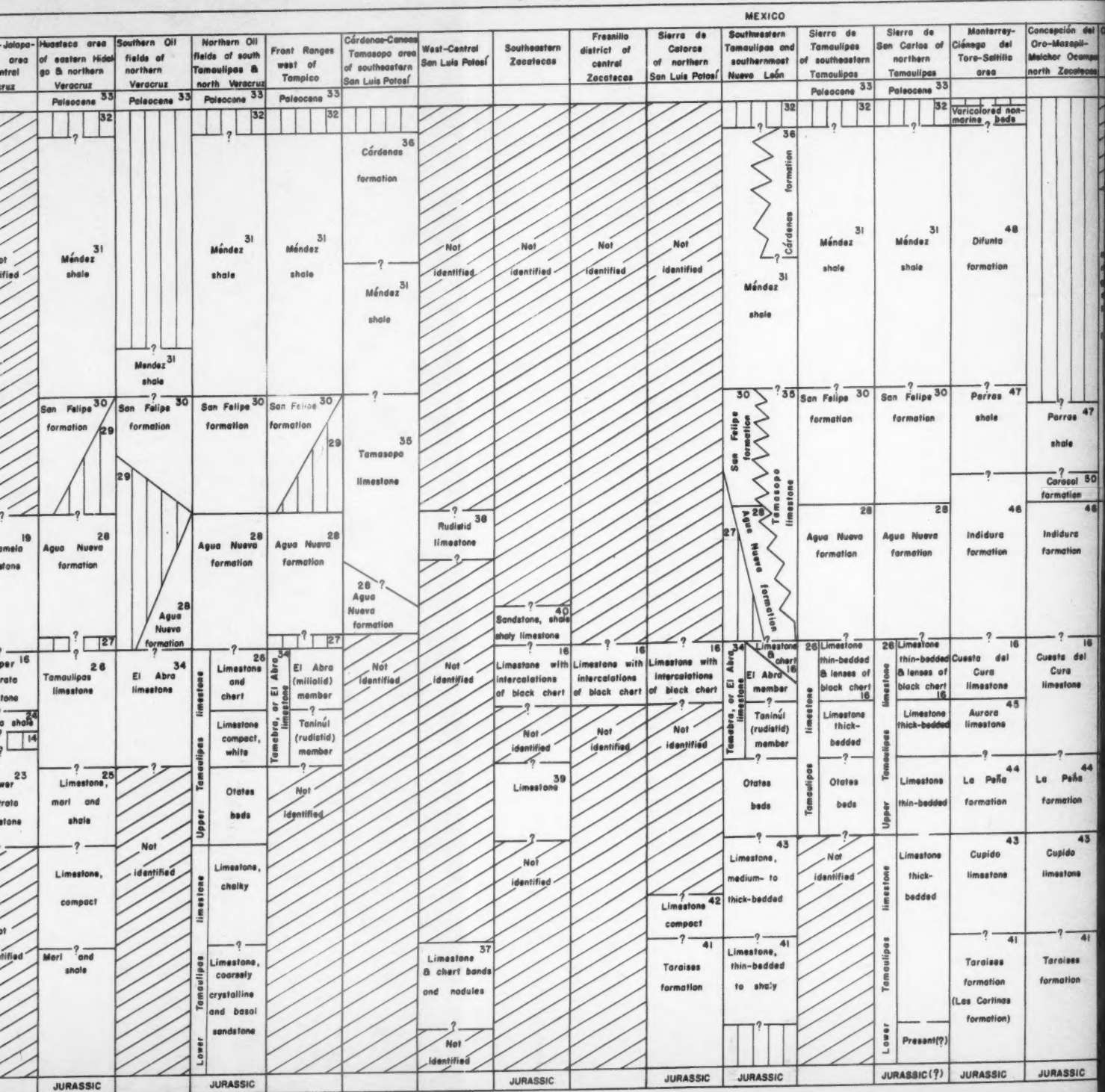
	Virgin Islands and St. Croix	Puerto Rico	Hispaniola (Santo Domingo and Haiti)	Jamaica	Cuba	Southern Nicaragua	El Salvador, Honduras, and southern Guatemala	British Honduras and northern Guatemala	Chiapas and Tabasco	Isthmus of Tehuantepec Eastern Veracruz & eastern Oaxaca	West-Central Oaxaca	Colla Jali
	Oligocene	Oligocene	Eocene	Eocene	Paleocene				Eocene			
	Not identified	Not identified	Not identified	Not identified	Not identified	Not identified	Not identified	Not identified	Not identified			
	?	?	?	?	?	?	?	?	?			
	1a Mount Eagle formation	2 Intrusive and extrusive rock dominant. Some limestone sandstone, shale and conglomerate.	3 Sandstone, shale, limestone, basalt flows, tuff, and volcanic breccia.	4 Blue Mountain series	7 Habana formation	8 Shale and sandstone with much volcanic material.	11 Esquias formation	12 San Cristóbal formation	12 San Cristóbal formation	Not identified	Not identified	
	? Not identified				Loma Yucatan limestone							
					? 6							
			?		?	?						
			Not identified	? Not identified	Tuff 5 formation	Not identified		?	?	?	?	
											19 Rudistid Limestone	
					Provincial limestone				10 Cobán limestone	10 Cobán limestone	10 Cobán limestone	
		? Not identified	? Probably present		Probably present		? 10 Limestone, marl, conglomeratic limestone	(also called Ixcoy and Comitán limestone)	(also called Sierra Madre and White limestone)		? 18 Limestone, thick-bedded & marly. Basal limestone breccia with gneiss & quartzite	
											? 14	
							? 9 Upper part of Metapán (Probably same as Tegucigalpa formation)	? 9 Upper part of Todos Santos beds	? 9 Tuxtla formation (Upper part of Todos Santos beds)	? 9 Chinameca limestone	13 Limestone, compact, gray	
											? Marly limestone and shale,	
			Schist and igneous rocks	Schist, gneiss, and marble	JURASSIC		JURASSIC	JURASSIC	JURASSIC	JURASSIC	JURASSIC	

CHART No. 10a - CORRELAT



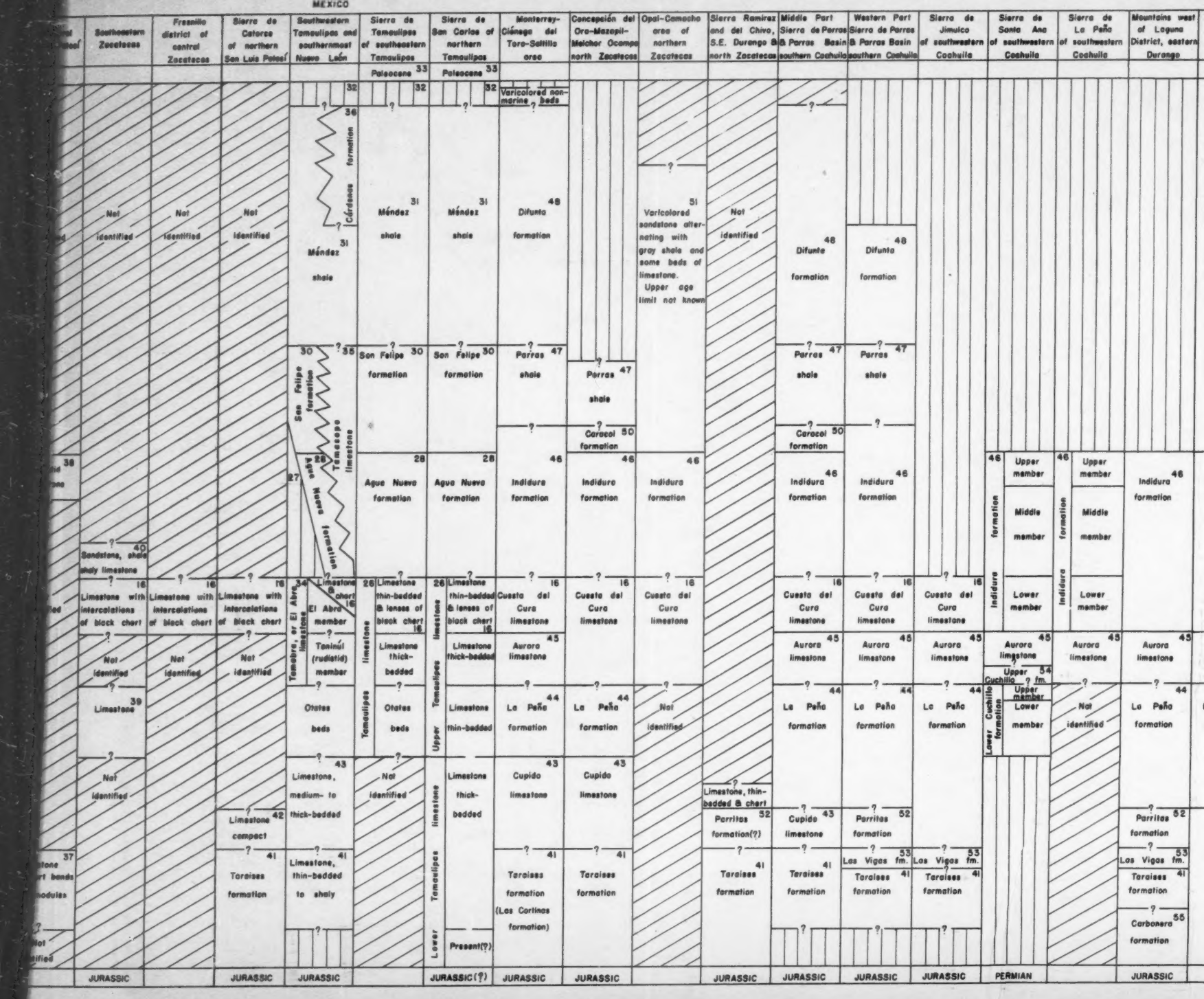
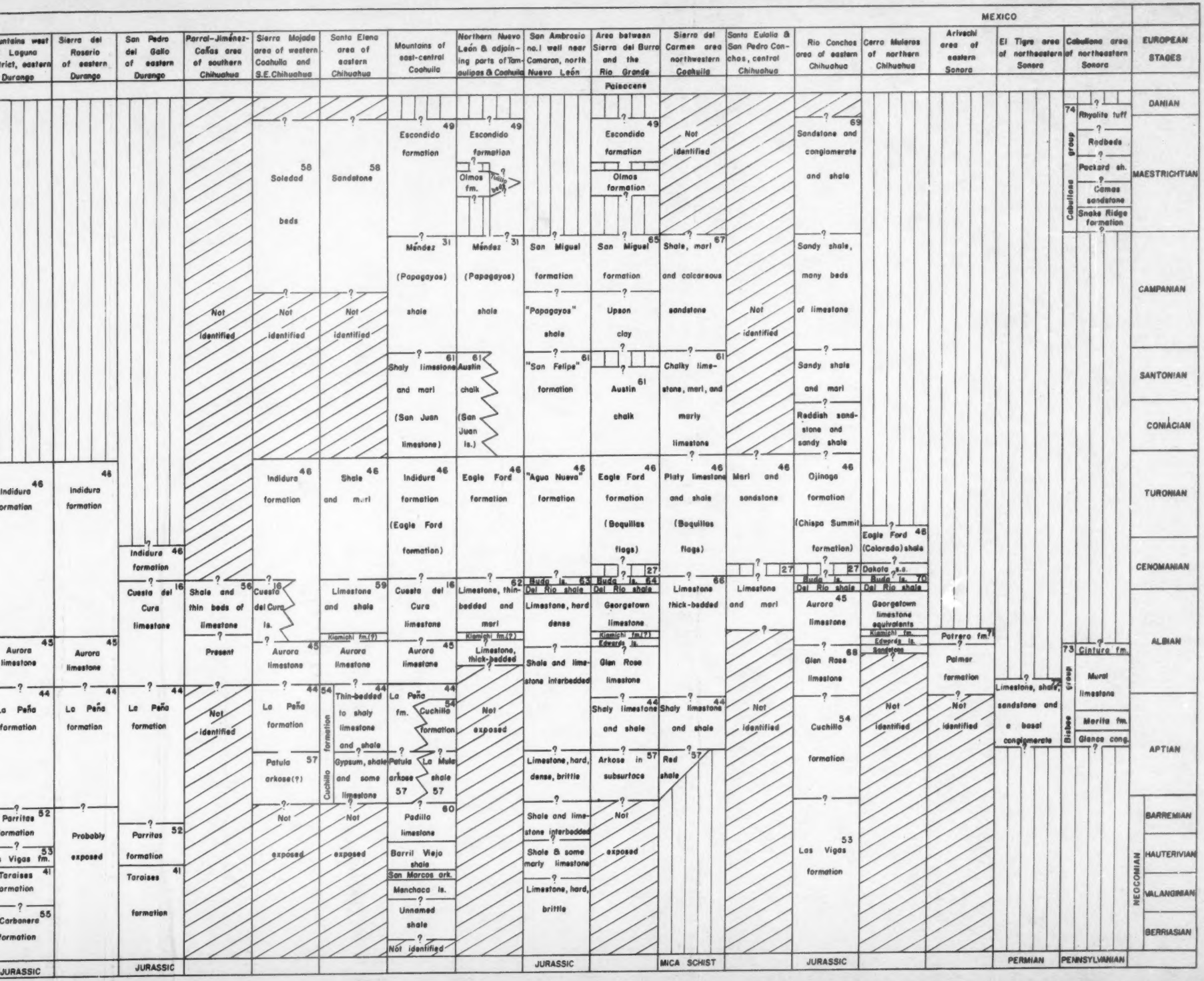
ELATION OF CRETACEOUS FORMATIONS OF THE GREATER ANTILLES, CENTRAL A

By Ralph W. Imlay



TIONS OF THE GREATER ANTILLES, CENTRAL AMERICA, AND MEXICO

By Ralph W. Imlay


MEXICO
Southeastern Zacatecas
Fresnillo district of central Zacatecas
Sierra de Catorce of northern San Luis Potosí
Southwestern Tamaulipas and southernmost Nuevo León
Sierra de Tamaulipas of southeastern Tamaulipas
Sierra de San Carlos of northern Tamaulipas
Monterrey–Ciénega del Toro–Saltillo area
Concepción del Oro–Mazapil–Melchor Ocampo north Zacatecas
Opal–Camacho area of northern Zacatecas
Sierra Ramírez and del Chivo, S.E. Durango & north Zacatecas
Middle Part Sierra de Parras & Parras Basin southern Coahuila
Western Part Sierra de Parras & Parras Basin southern Coahuila
Sierra de Jimulco of southwestern Coahuila
Sierra de Santa Ana of southwestern Coahuila
Sierra de La Peña of southwestern Coahuila
Mountains west of Laguna District, eastern Durango
Paleocene 33
Not identified
Méndez shale
Cárdenas formation
Méndez shale
Méndez shale
Difunta formation
Variegated non-marine beds
Variegated sandstone alternating with gray shale and some beds of limestone. Upper age limit not known
Not identified
Difunta formation
Difunta formation
Parras shale
Parras shale
Parras shale
Parras shale
Cerrocol formation
Cerrocol formation
San Felipe formation
San Felipe formation
San Felipe formation
Tamaspe limestone
Indidura formation
Agua Nueva formation
Agua Nueva formation
Indidura formation
Indidura formation
Indidura formation
Indidura formation
Indidura formation
Upper member
Middle member
Lower member
Sandstone, shale, shaly limestone
Limestone with intercalations of black chert
Limestone with intercalations of black chert
Limestone with intercalations of black chert
Tamabra, or El Abra limestone
El Abra member
Tamaulipas limestone
Limestone & chert
Limestone thin-bedded & lenses of black chert
Limestone thin-bedded & lenses of black chert
Cuesta del Cura limestone
Cuesta del Cura limestone
Cuesta del Cura limestone
Cuesta del Cura limestone
Cuesta del Cura limestone
Cuesta del Cura limestone
Aurora limestone
Aurora limestone
Aurora limestone
Aurora limestone
Aurora limestone
Aurora limestone
Upper Cuchillo ? fm.
Lower Cuchillo formation
Upper member
Lower member
Toninil (rudistid) member
Limestone thick-bedded
Limestone thick-bedded
Limestone thick-bedded
Otates beds
Otates beds
La Peña formation
La Peña formation
La Peña formation
La Peña formation
La Peña formation
La Peña formation
Not identified
Not identified
Not identified
Not identified
Limestone, medium- to thick-bedded
Limestone, thin-bedded to shaly
Limestone compact
Taraises formation
Taraises formation
Taraises formation

Prepared under the auspices of the Committee on Stratigraphy of the National Research Council, Carl O. Dunbar, *Chairman*.